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(12) **United States Patent**
**Ichikawa et al.**

(10) **Patent No.: US 12,085,707 B2**
(45) **Date of Patent: Sep. 10, 2024**

(54) **WIDE-ANGLE OPTICAL SYSTEM AND IMAGE PICKUP APPARATUS USING THE SAME**

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(72) Inventors: **Keisuke Ichikawa**, Tama (JP); **Takashi Fujikura**, Hamura (JP); **Shinichi Mihara**, Tama (JP); **Yoshihiro Uchida**, Hachioji (JP)

(73) Assignee: **OLYMPUS CORPORATION**, Tokyo (JP)

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(21) Appl. No.: **17/189,353**

(22) Filed: **Mar. 2, 2021**

(65) **Prior Publication Data**

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**Related U.S. Application Data**

(63) Continuation of application No. PCT/JP2019/008033, filed on Mar. 1, 2019.

(51) **Int. Cl.**

| | |
|---|---|
| ***G02B 15/14*** | (2006.01) |
| ***G02B 23/24*** | (2006.01) |

(52) **U.S. Cl.**
CPC ... ***G02B 23/243*** (2013.01); ***G02B 15/143507*** (2019.08)

(58) **Field of Classification Search**
CPC ...................... G02B 23/243; G02B 15/143507
See application file for complete search history.

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*Primary Examiner* — Wen Huang
(74) *Attorney, Agent, or Firm* — Holtz, Holtz & Volek PC

(57) **ABSTRACT**

A wide-angle optical system is a wide-angle optical system having a lens component, and includes in order from an object side, a first lens unit having a negative refractive power, a second lens unit having a negative refractive power, and a third lens unit having a positive refractive power. At the time of carrying out a focal-position adjustment from a far point to a near point, the second lens unit is moved from a first position toward a second position. The third lens unit includes not less than three lens components. Not less than three lens components include a first lens component and a second lens component. Each of the first lens component and the second lens component has a positive refractive power, and following conditional expression (1) is satisfied:

$$0.8<f3L12/fL<6.0 \qquad (1).$$

**34 Claims, 33 Drawing Sheets**

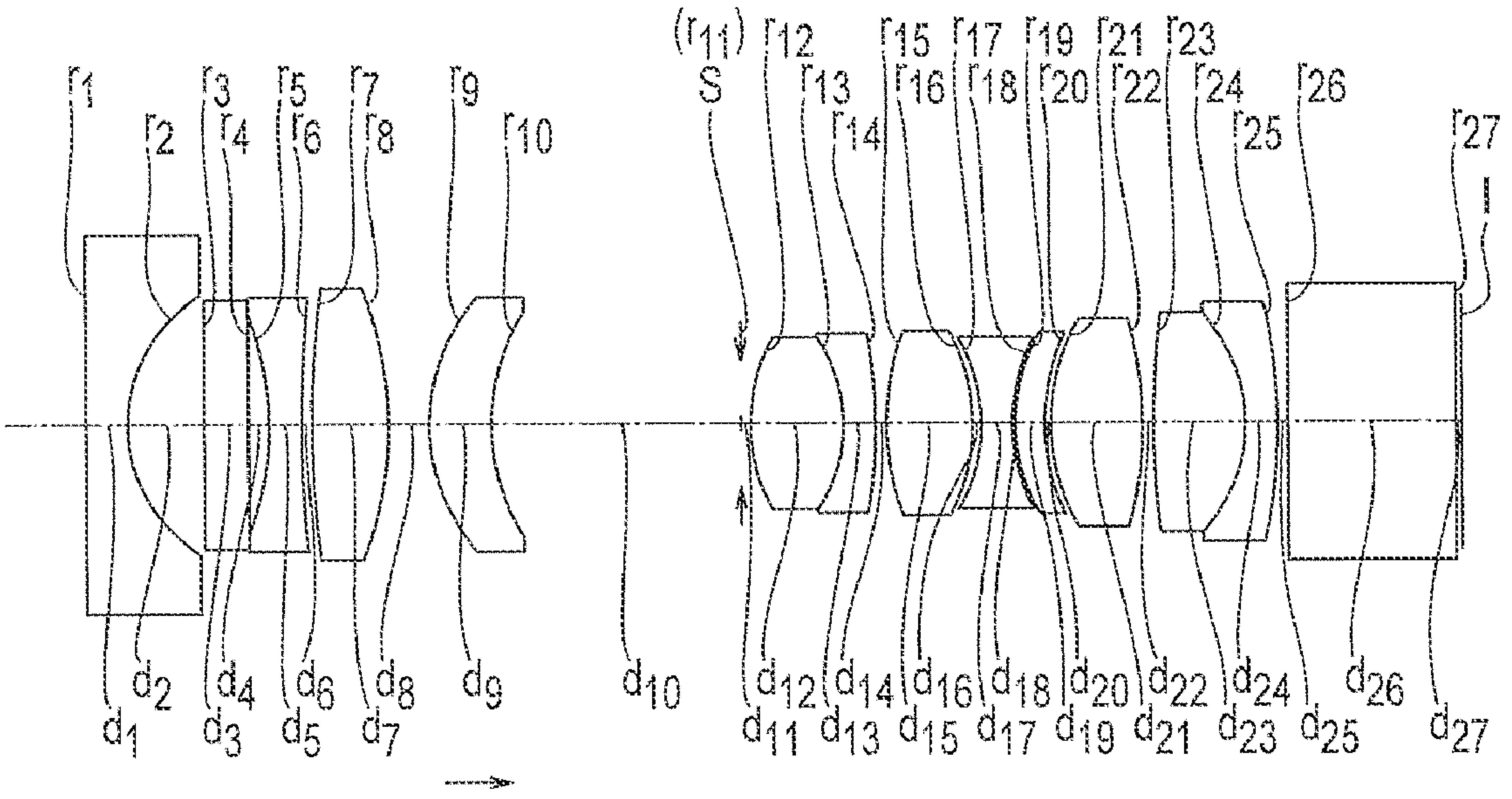

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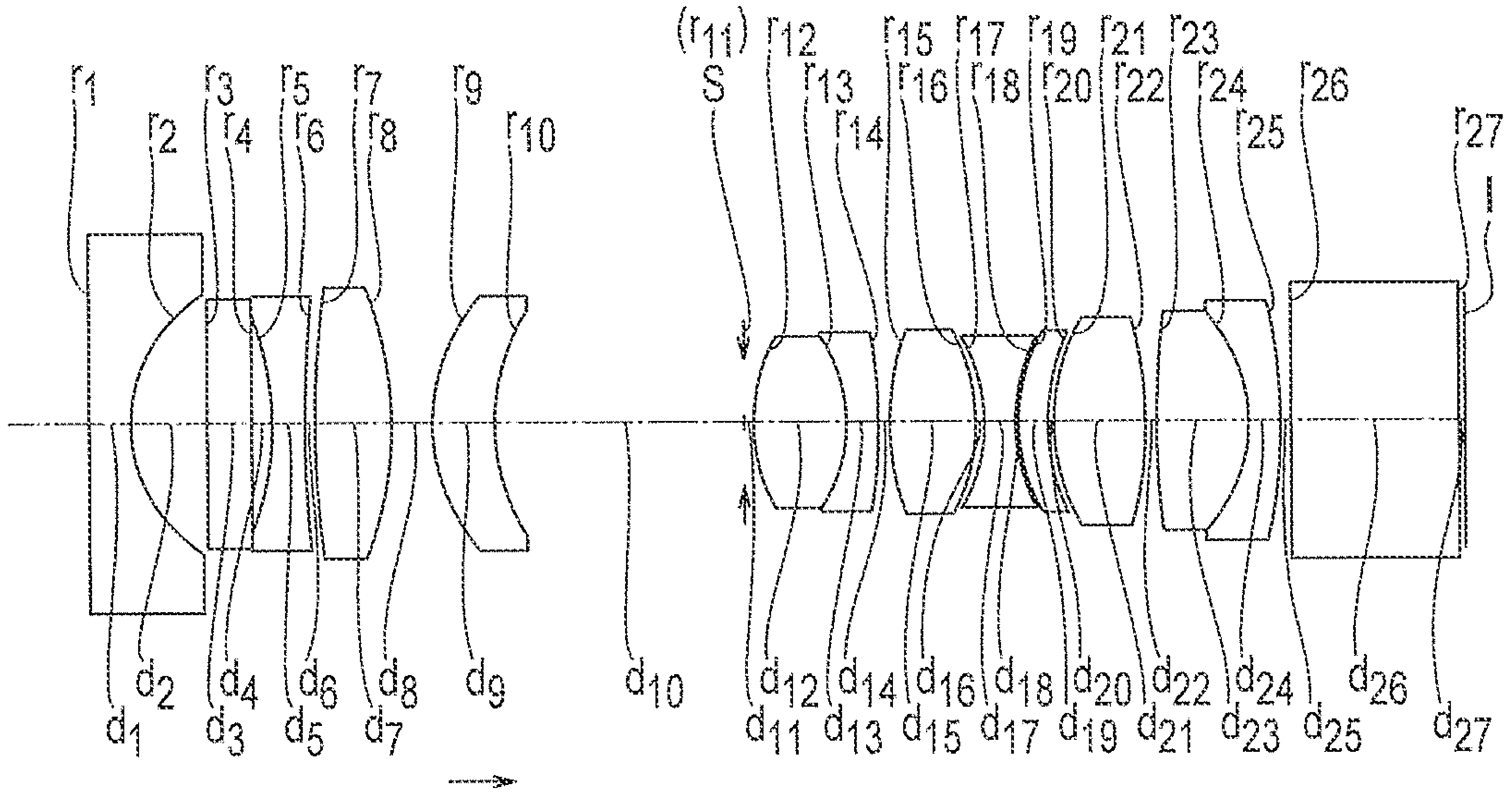
FIG. 1A



r1
r2
r3
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r5
r6
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r8
r9
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(r11)
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r14
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r16
r17
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r20
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r23
r24
r25
r26
r27
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d2
d3
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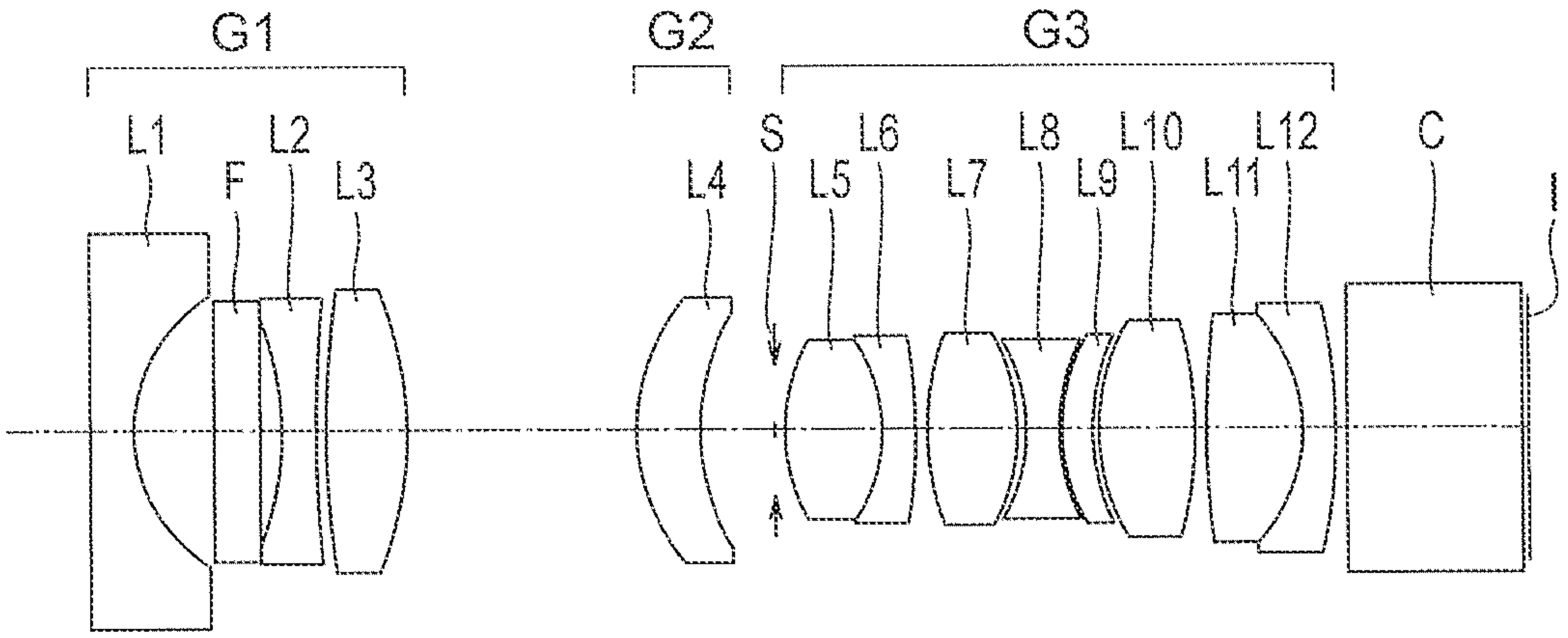
FIG. 1B



G1
G2
G3
L1
F
L2
L3
L4
S
L5
L6
L7
L8
L9
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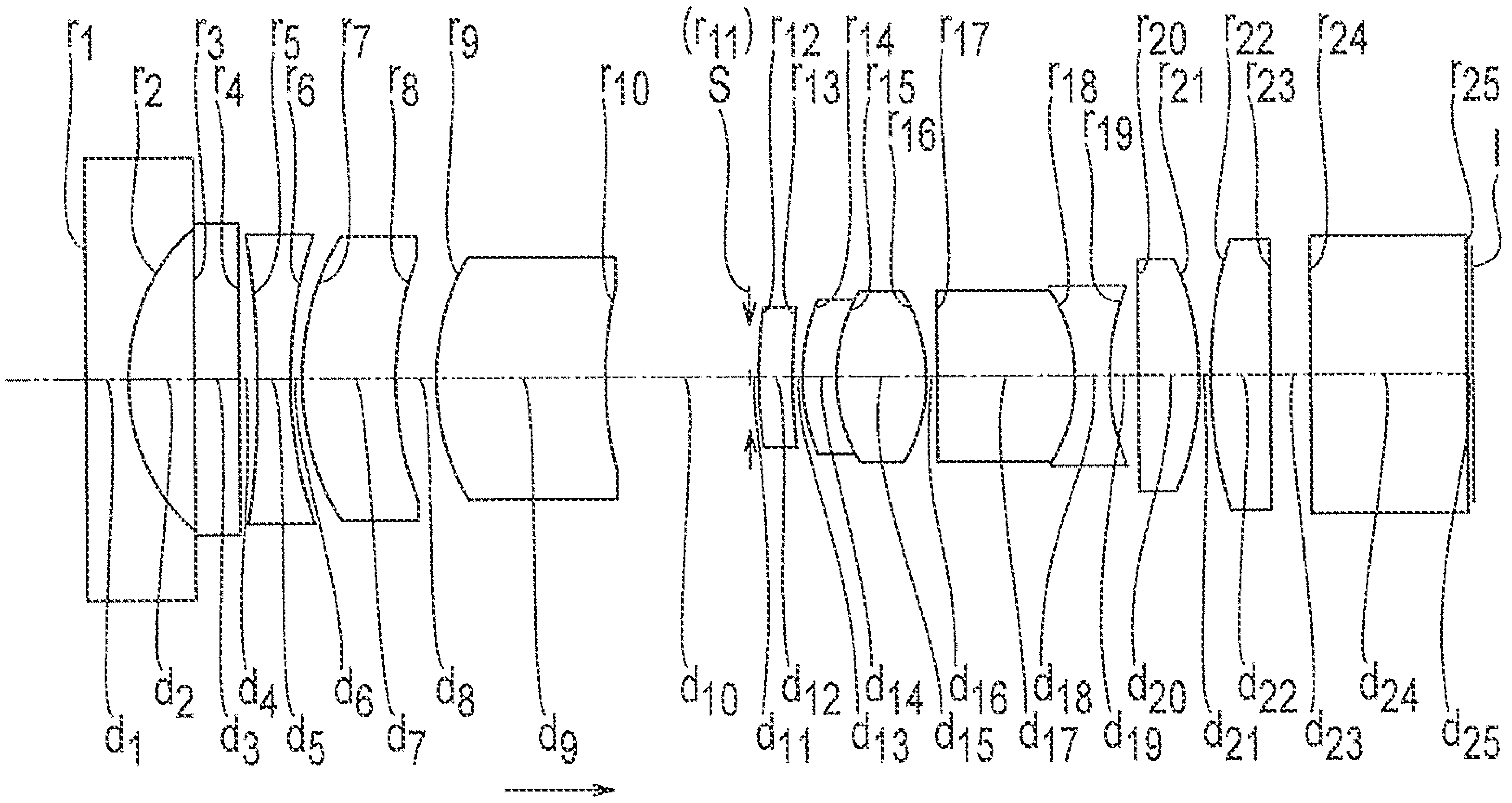
L11
L12
C
I

FIG. 2A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r2
r3
r4
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r6
r7
r8
r9
r10
(r11)
S
r12
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r14
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r21
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r23
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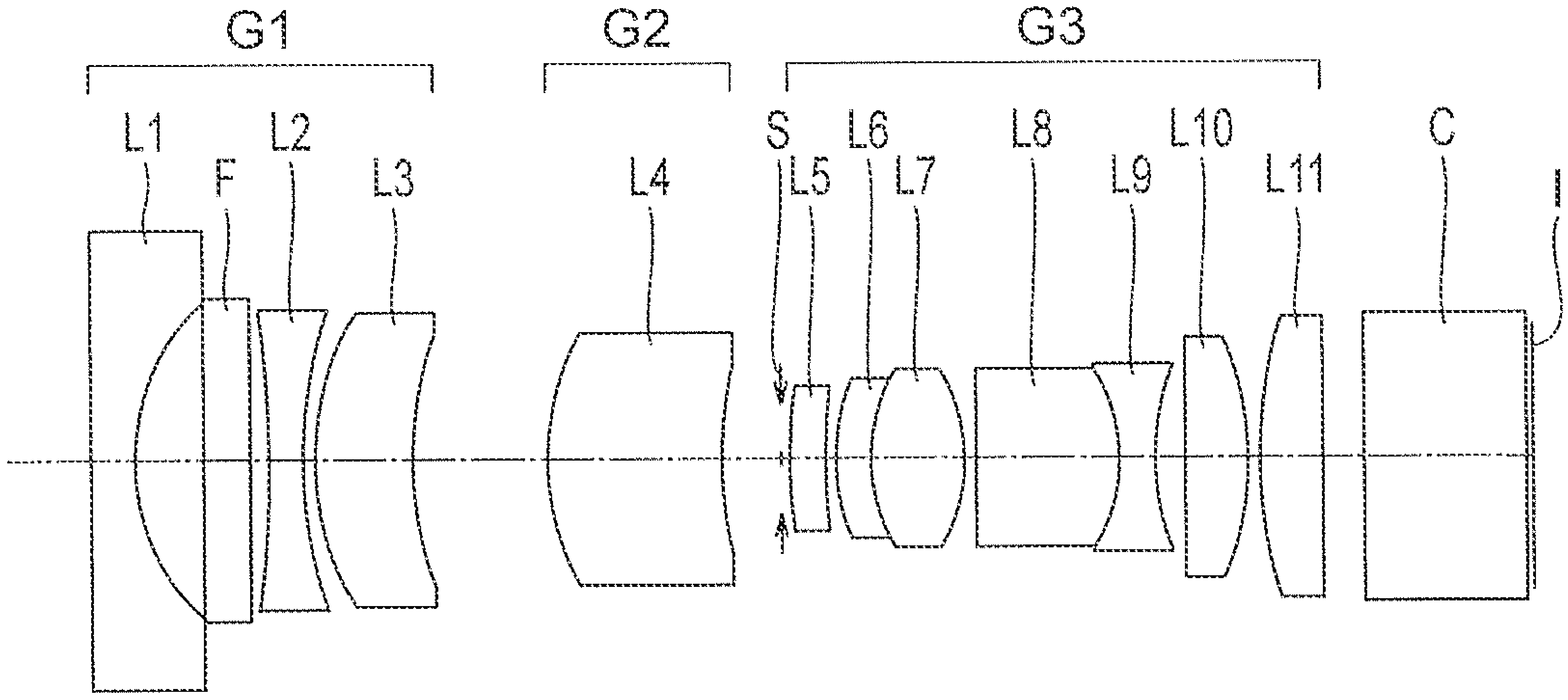
d25

FIG. 2B


G1
G2
G3
L1
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L2
L3
L4
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L5
L6
L7
L8
L9
L10
L11
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I

FIG. 3A

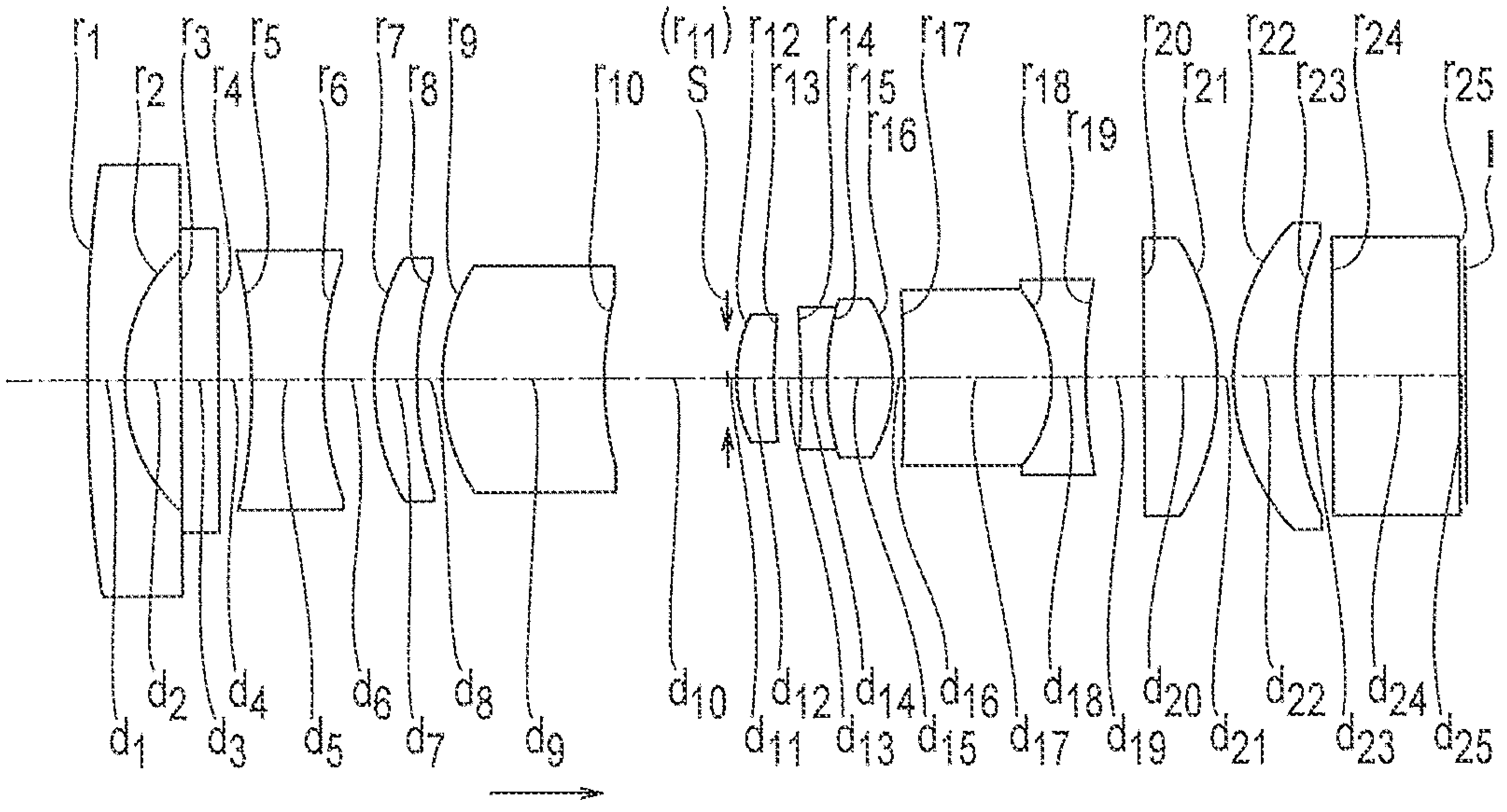

$r_1$ $r_2$ $r_3$ $r_4$ $r_5$ $r_6$ $r_7$ $r_8$ $r_9$ $r_{10}$
$(r_{11})$ S
$r_{12}$ $r_{13}$ $r_{14}$ $r_{15}$ $r_{16}$ $r_{17}$ $r_{18}$ $r_{19}$ $r_{20}$ $r_{21}$ $r_{22}$ $r_{23}$ $r_{24}$ $r_{25}$
I
$d_1$ $d_2$ $d_3$ $d_4$ $d_5$ $d_6$ $d_7$ $d_8$ $d_9$ $d_{10}$ $d_{11}$ $d_{12}$ $d_{13}$ $d_{14}$ $d_{15}$ $d_{16}$ $d_{17}$ $d_{18}$ $d_{19}$ $d_{20}$ $d_{21}$ $d_{22}$ $d_{23}$ $d_{24}$ $d_{25}$

FIG. 3B

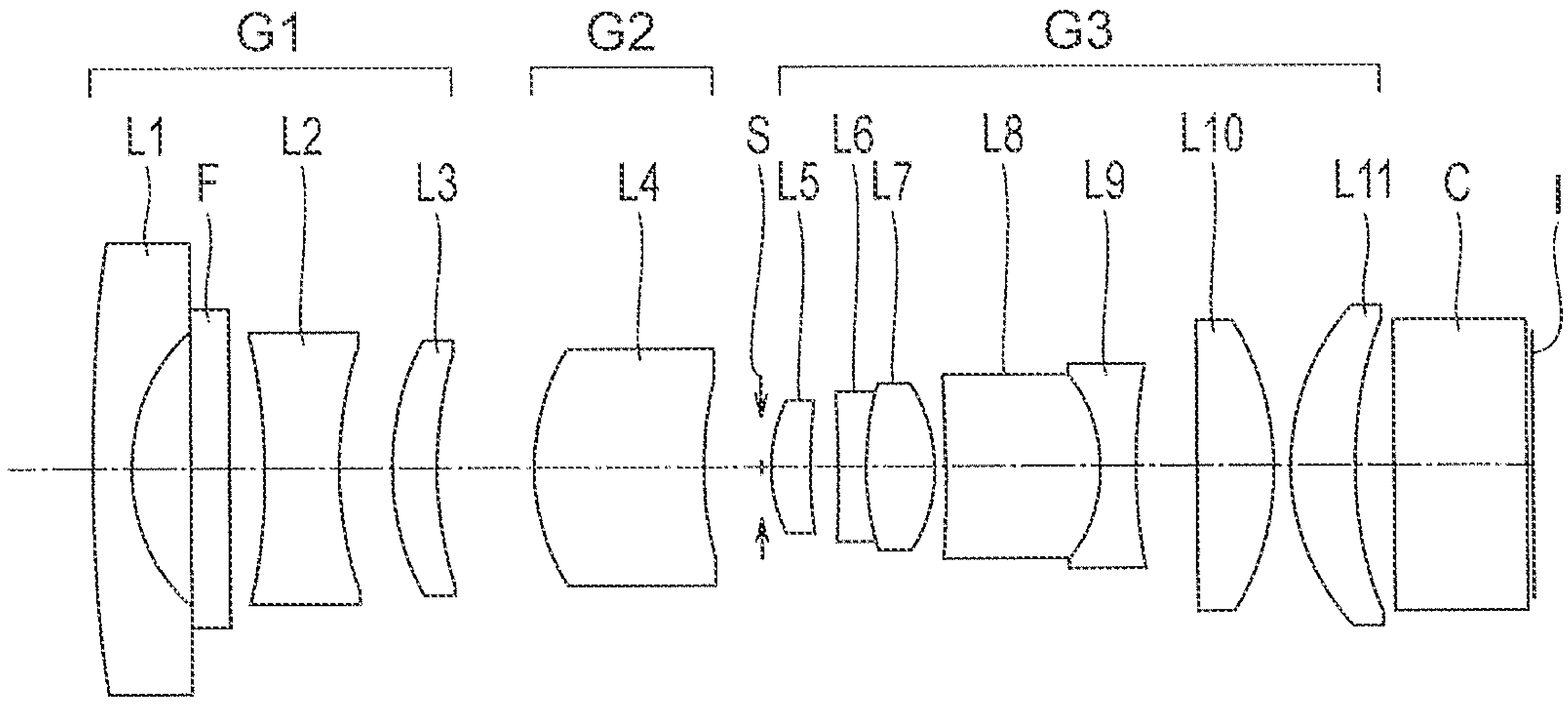
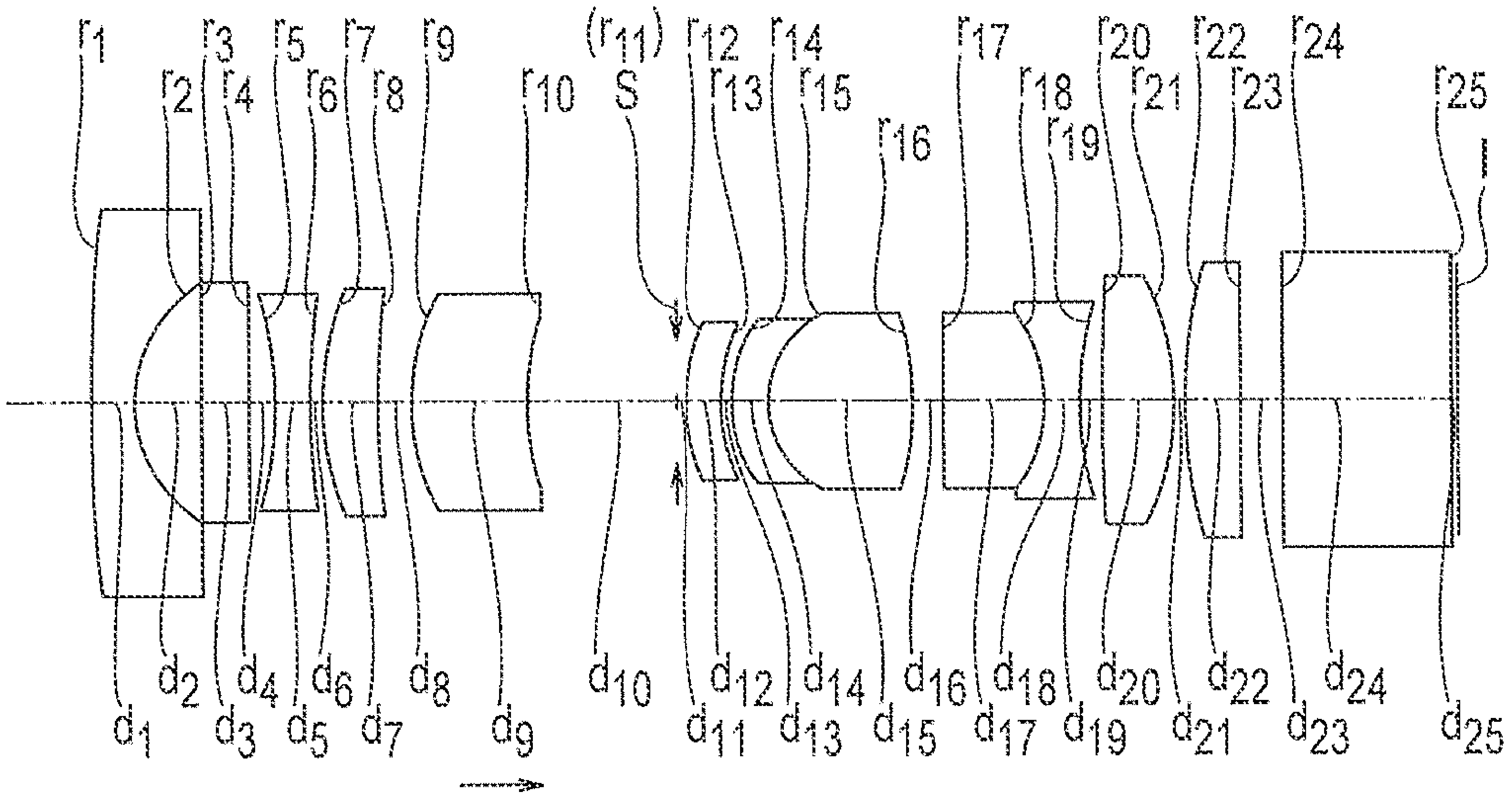

G1
G2
G3
L1
F
L2
L3
L4
S
L5
L6
L7
L8
L9
L10
L11
C
I

FIG. 4A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r5
r6
r7
r8
r9
r10
(r11)
S
r12
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r25
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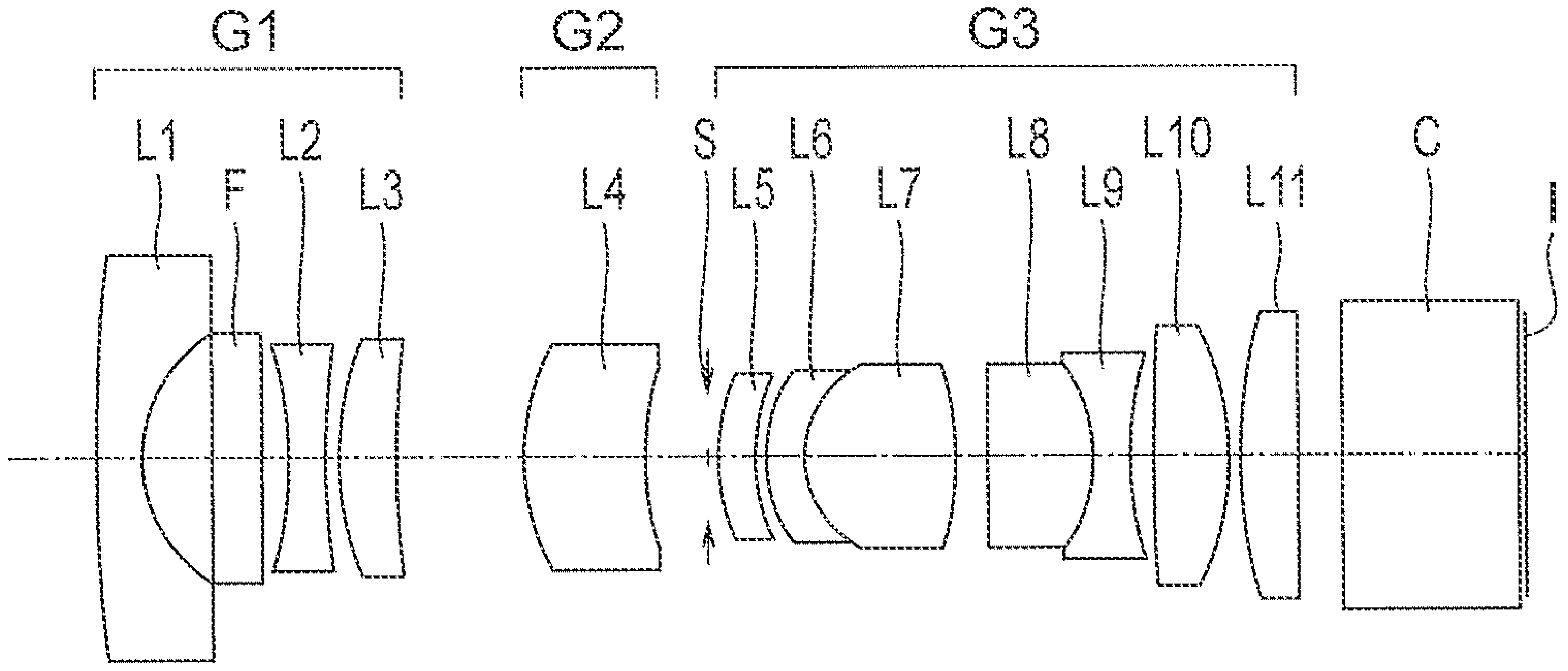
FIG. 4B


G1
G2
G3
L1
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L4
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L5
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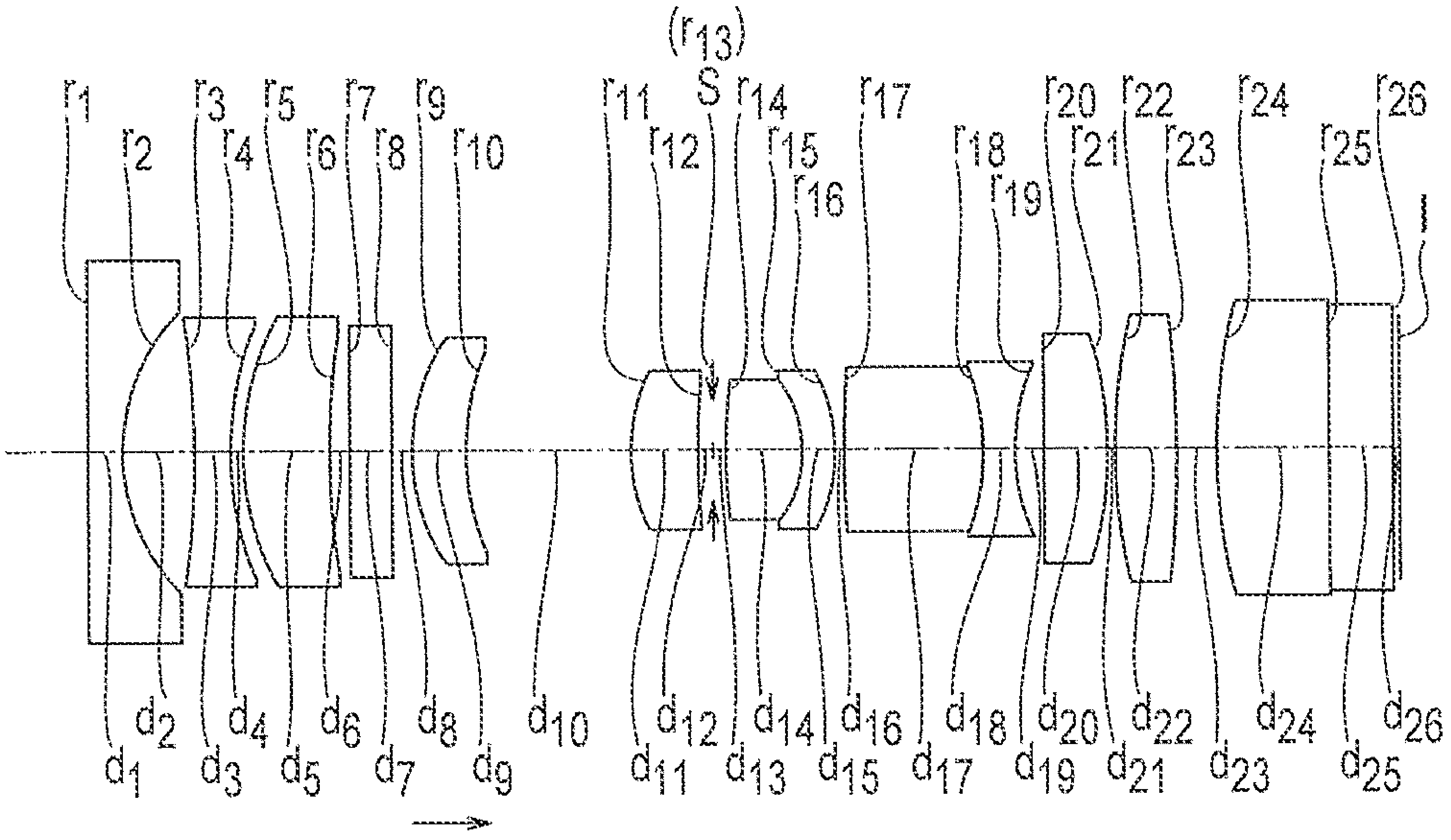
FIG. 5A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r16
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r25
r26
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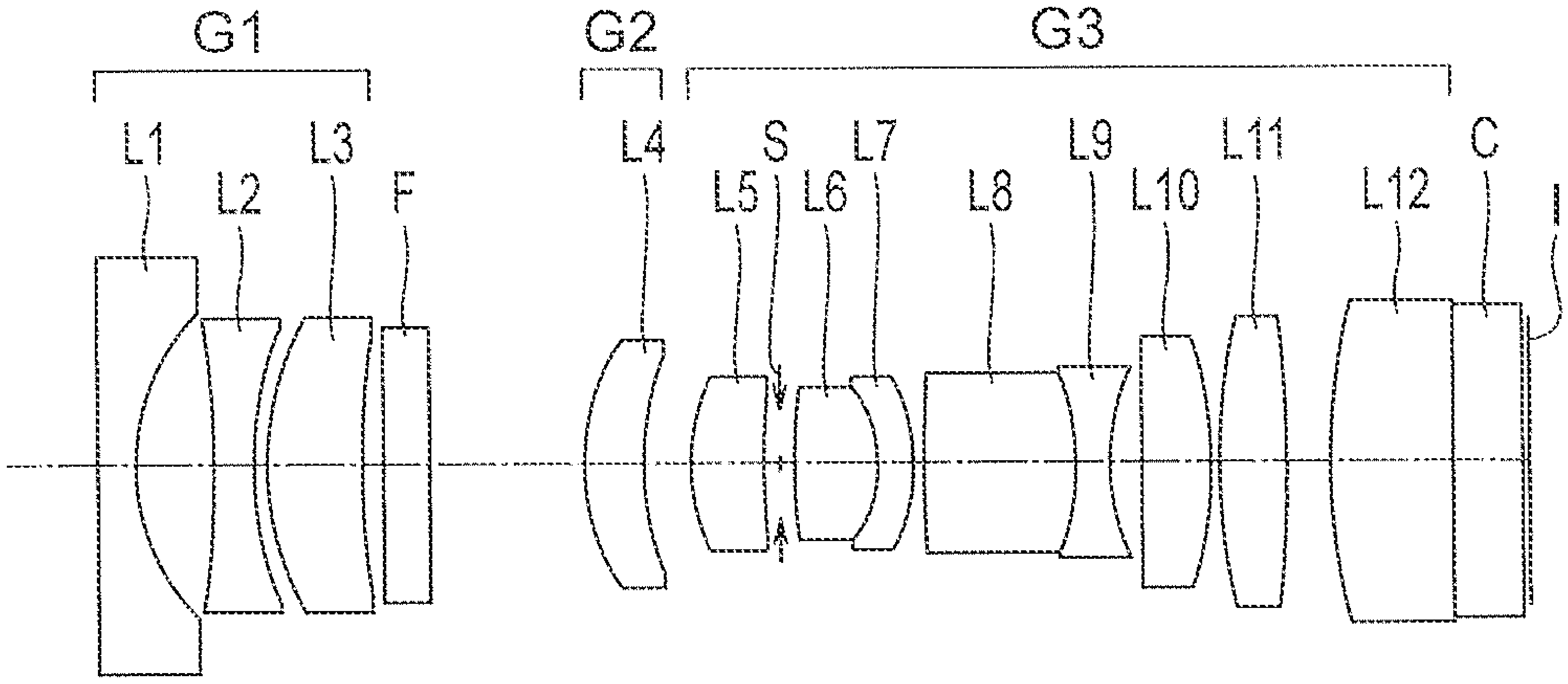
FIG. 5B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G2
G3
L1
L2
L3
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L5
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L11
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FIG. 6A

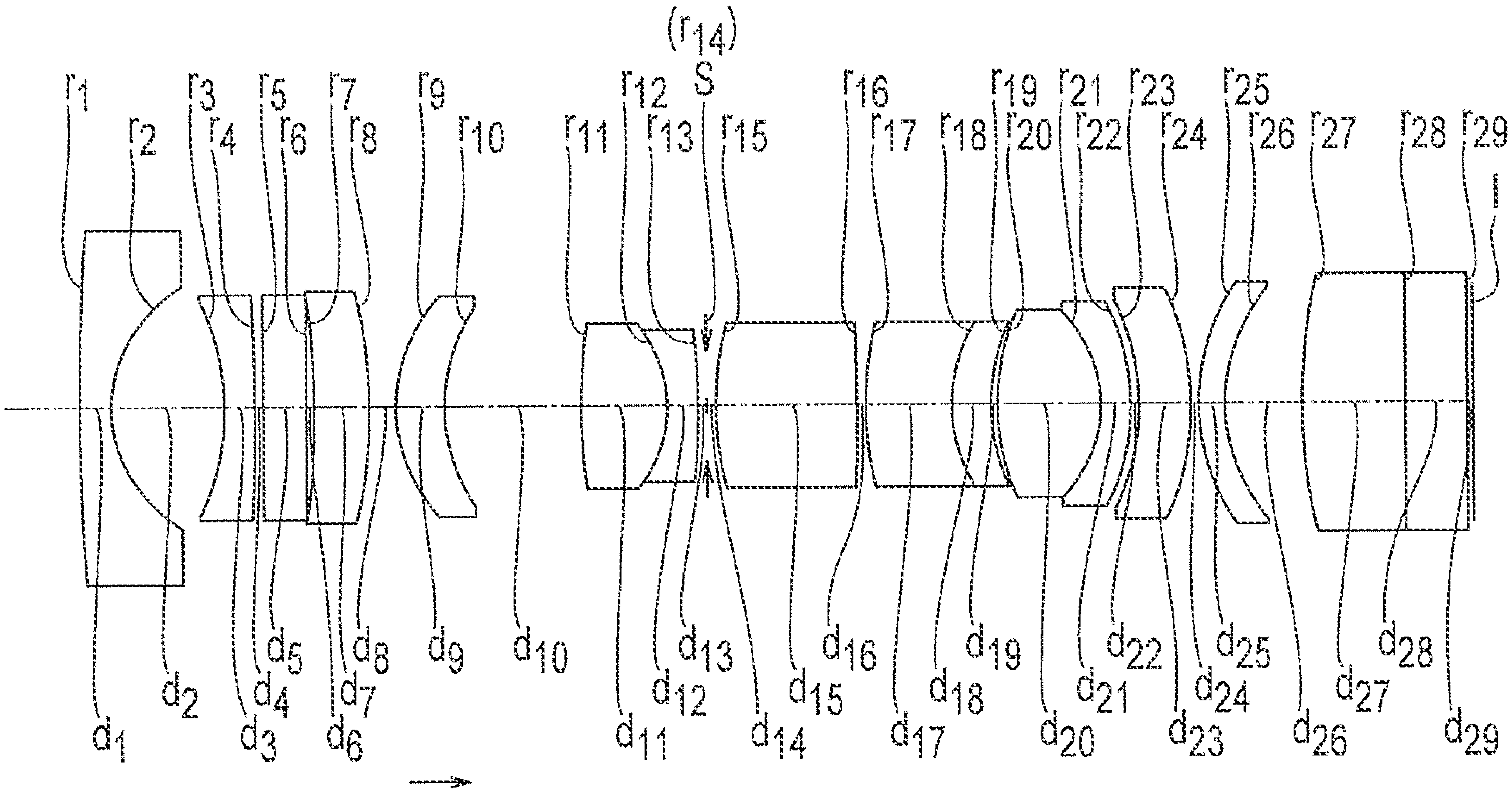
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FIG. 6B

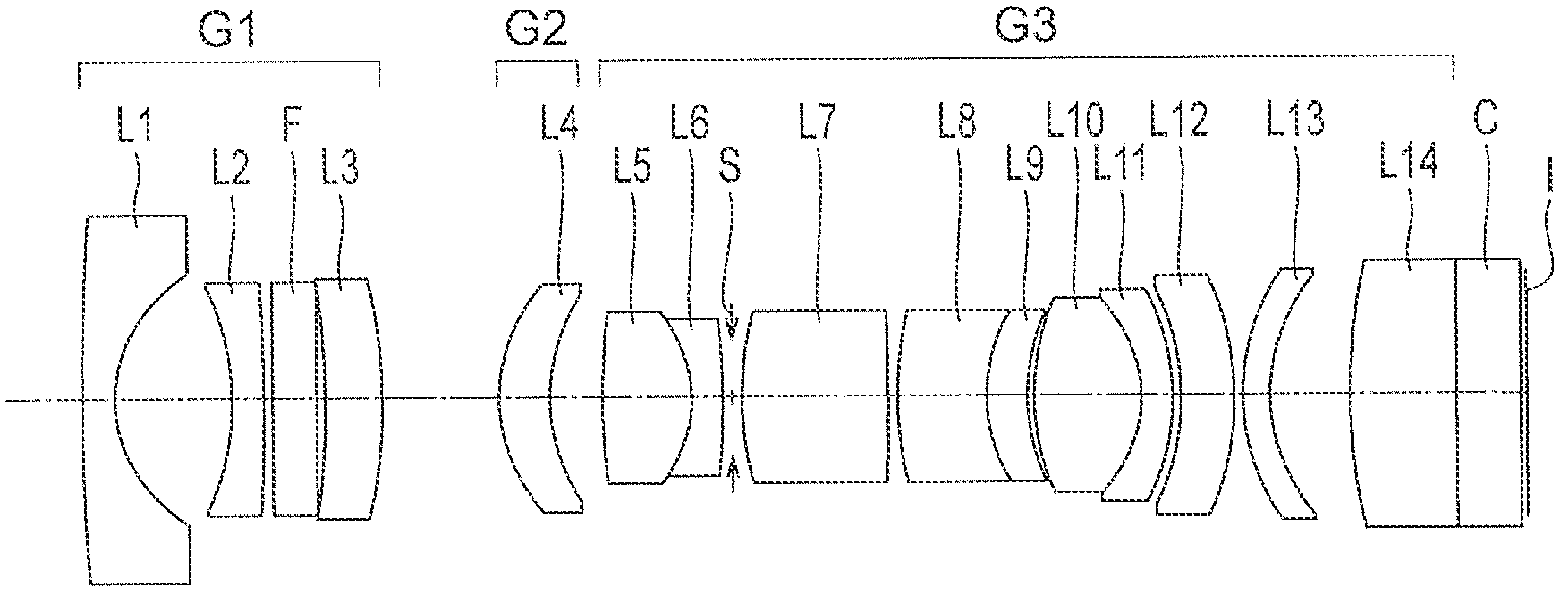
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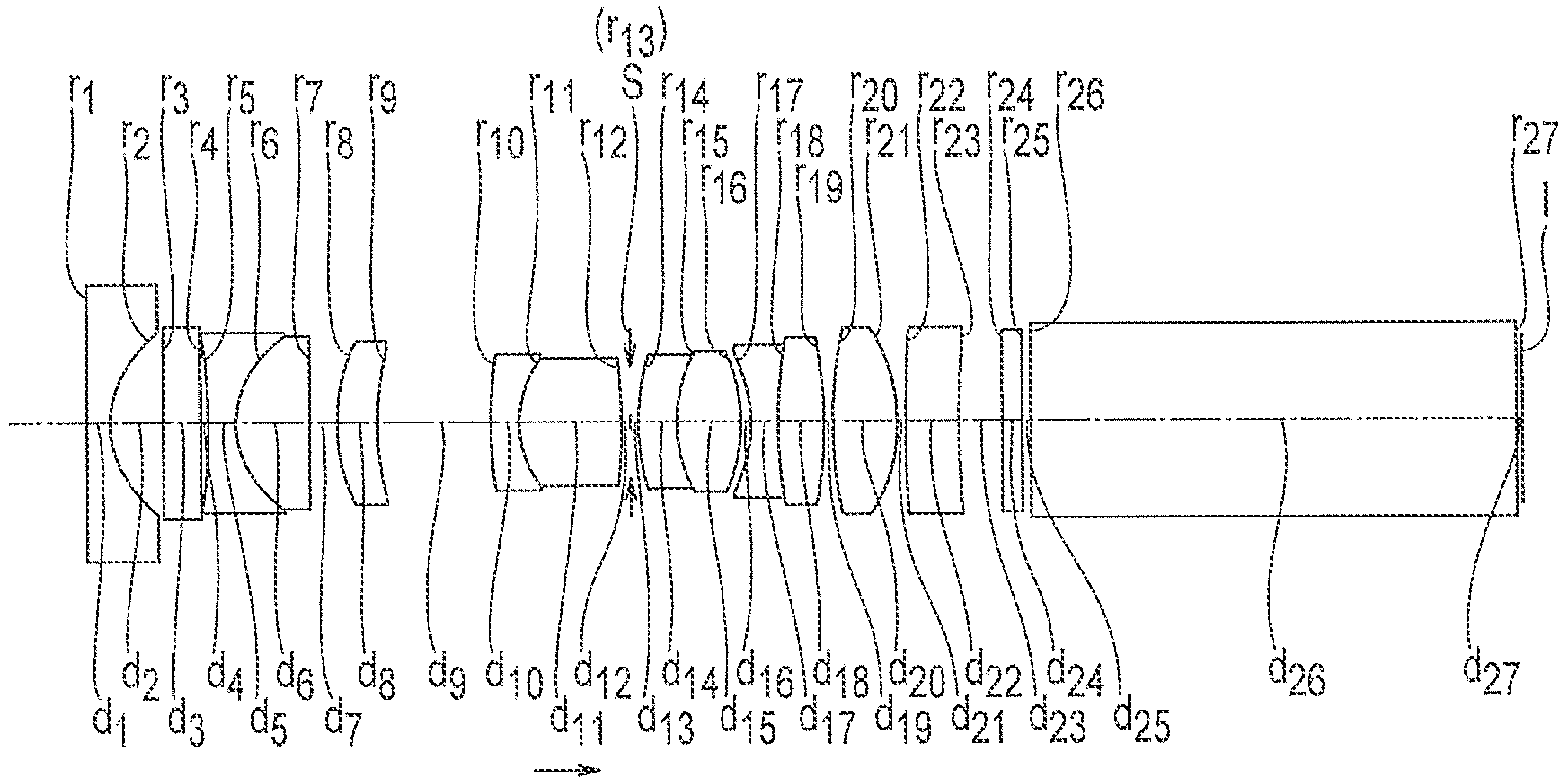
FIG. 7A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d1
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FIG. 7B

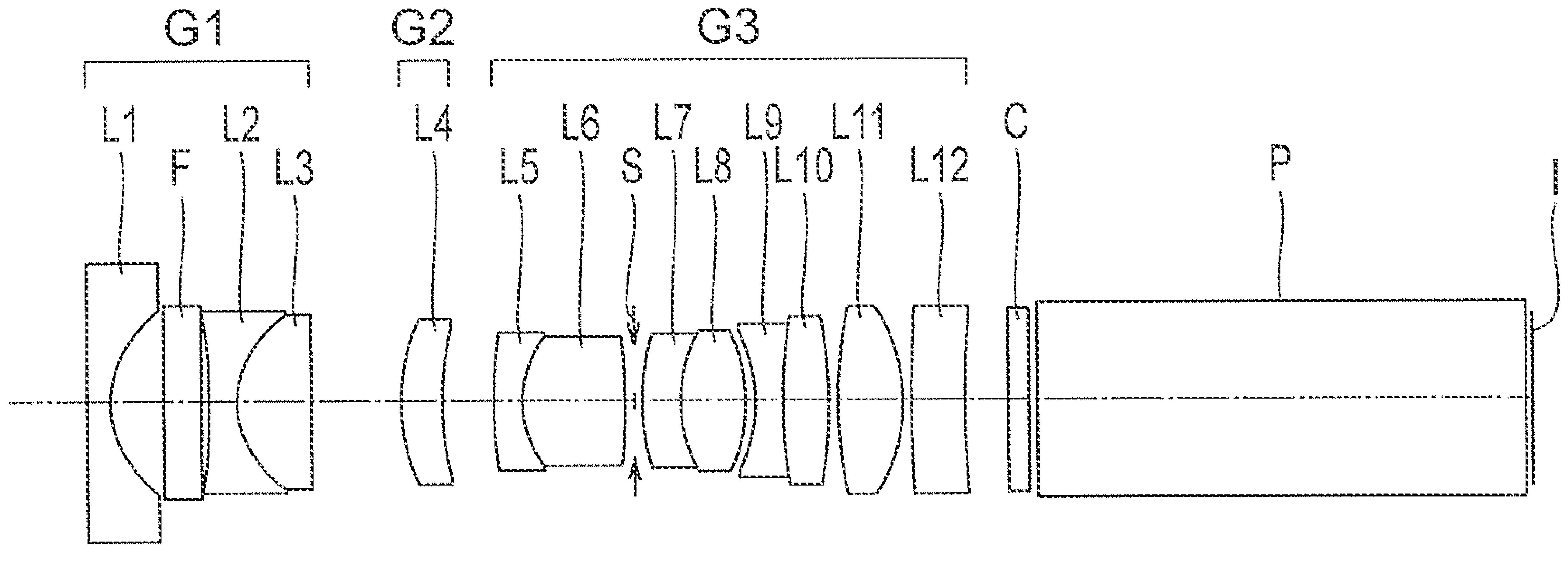
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FIG. 8A

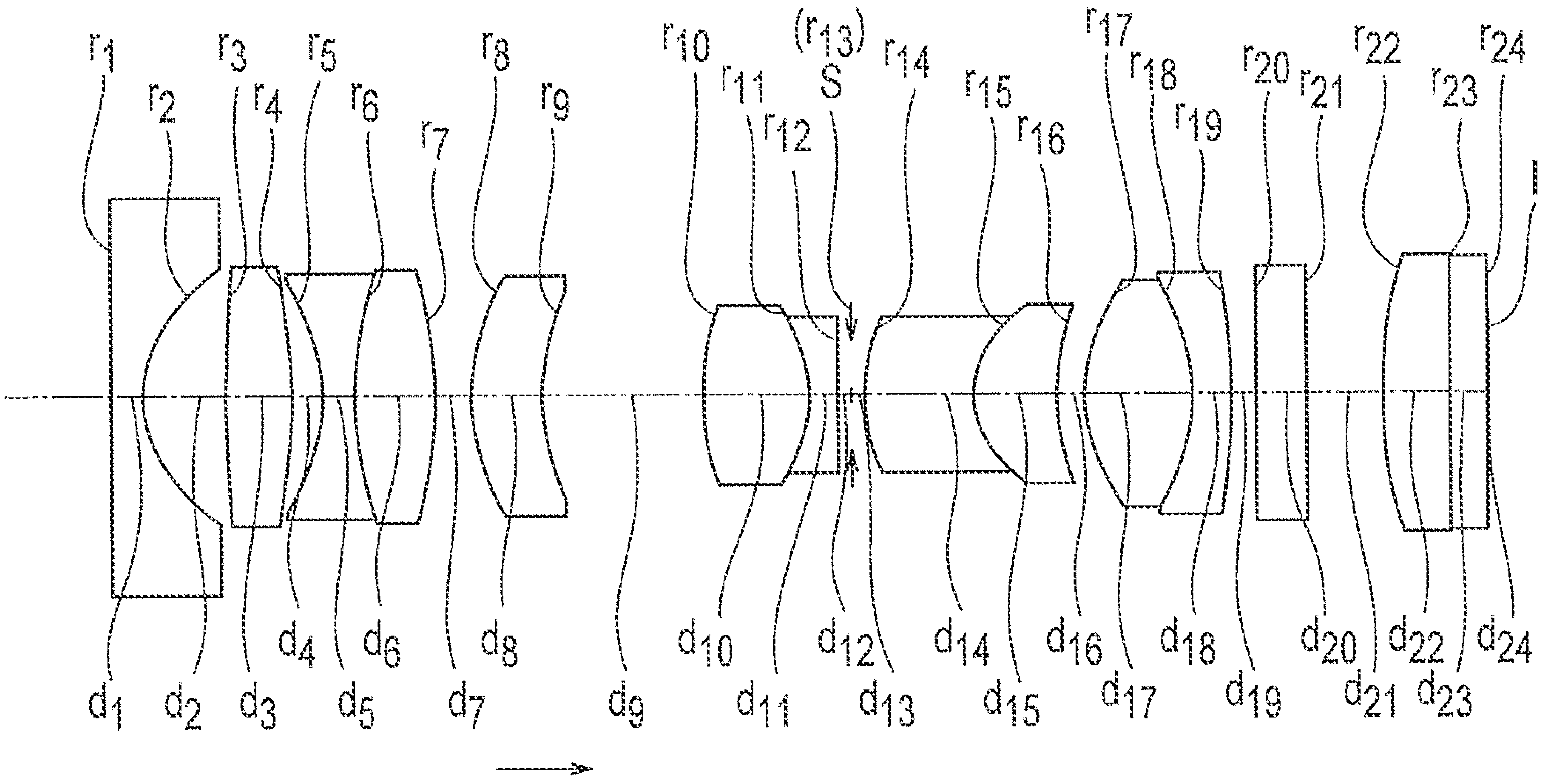
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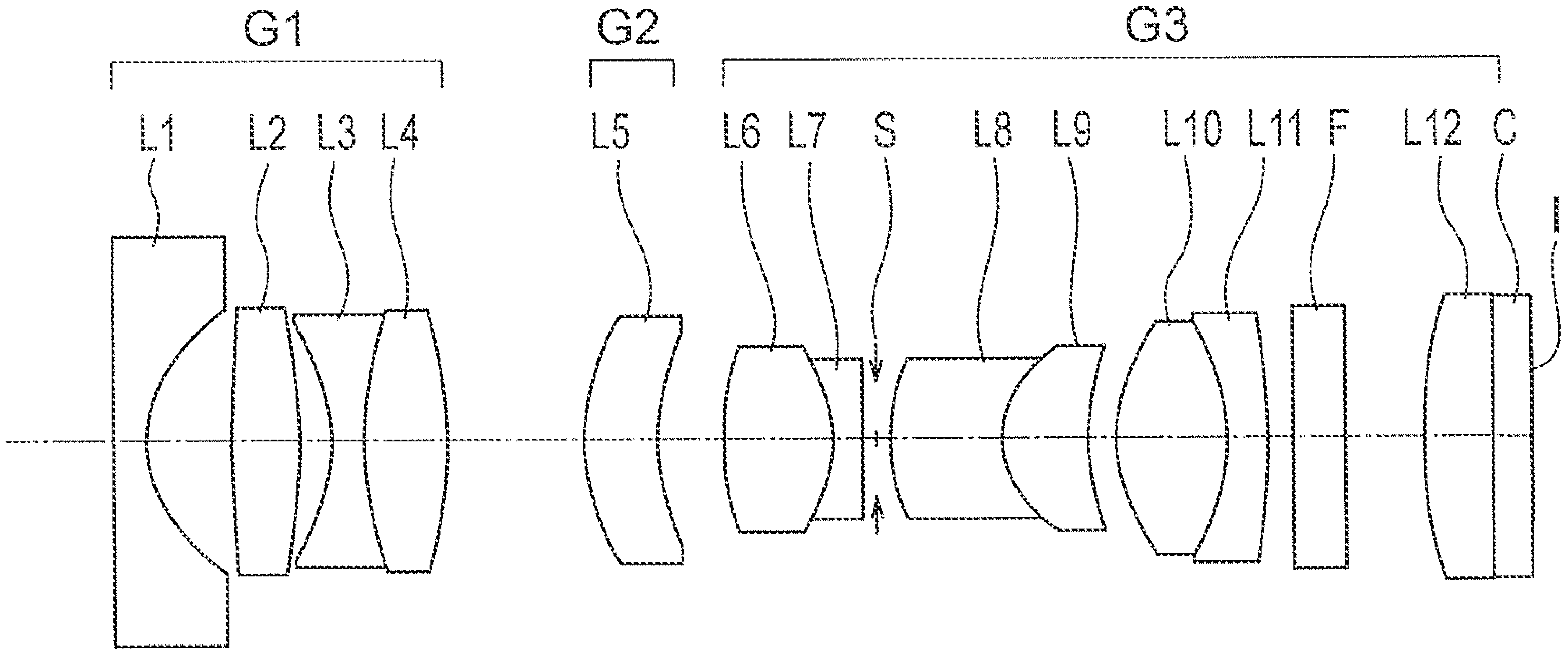
FIG. 8B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L12
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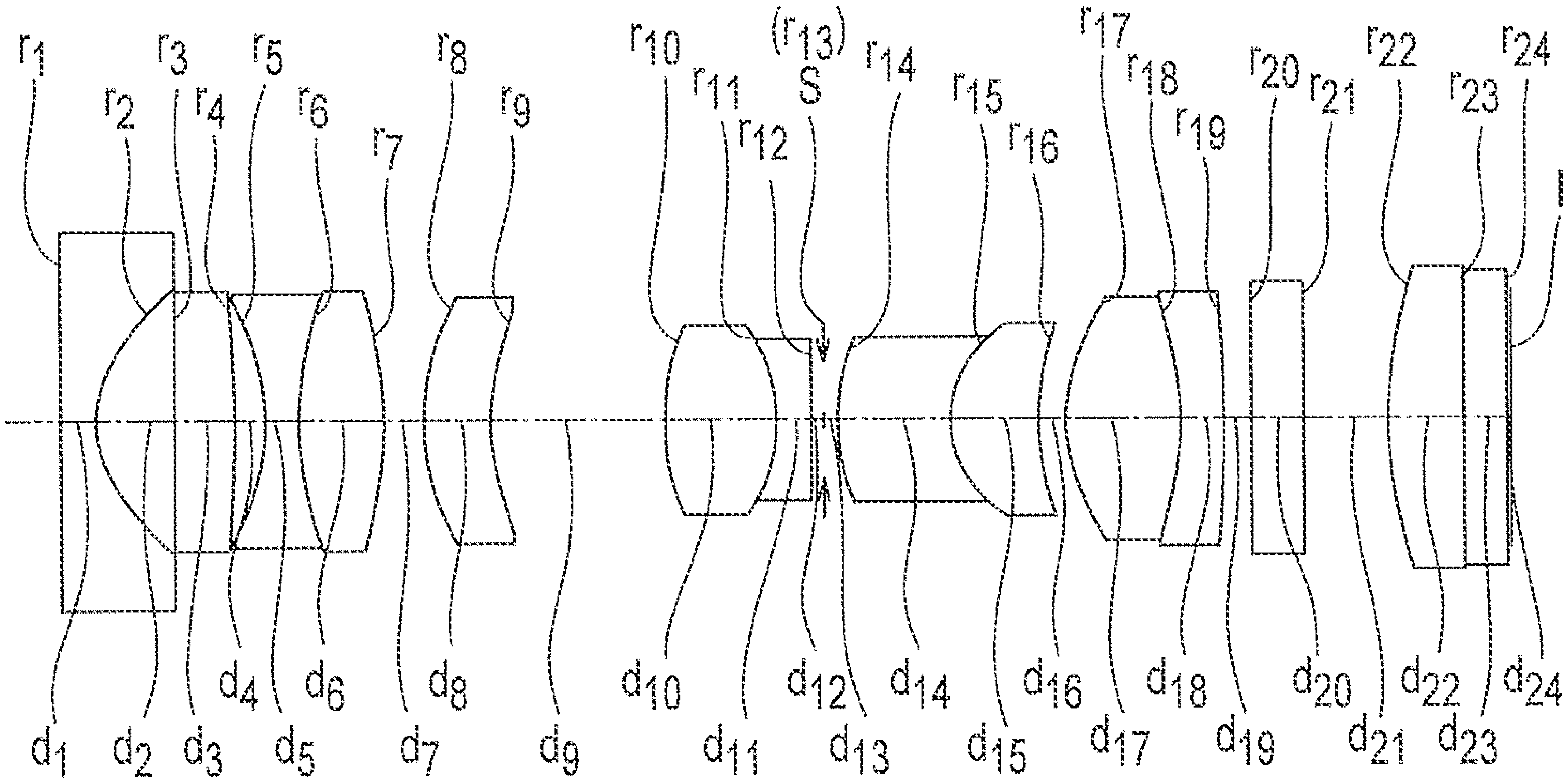
FIG. 9A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r19
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r21
r22
r23
r24
I
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d4
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d24

FIG. 9B

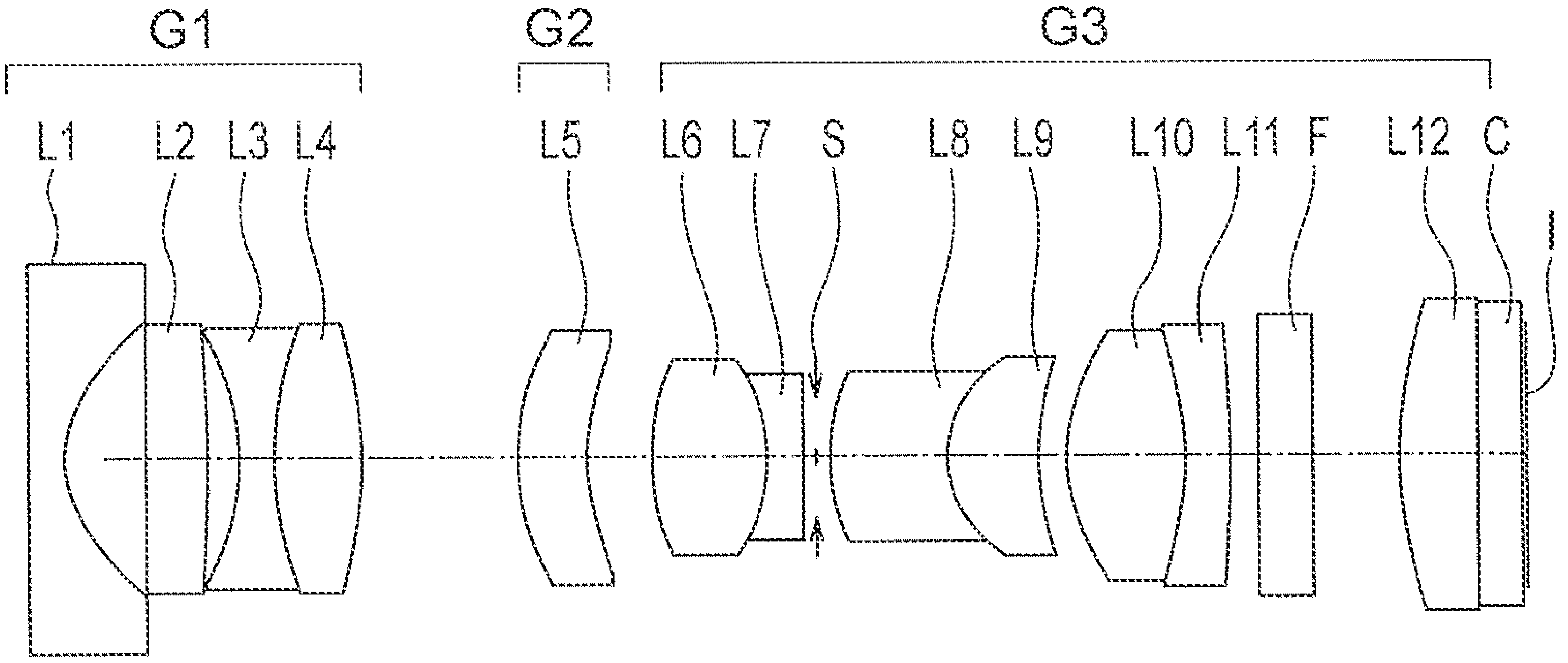

G1
G2
G3
L1
L2
L3
L4
L5
L6
L7
S
L8
L9
L10
L11
F
L12
C
I

FIG. 10A

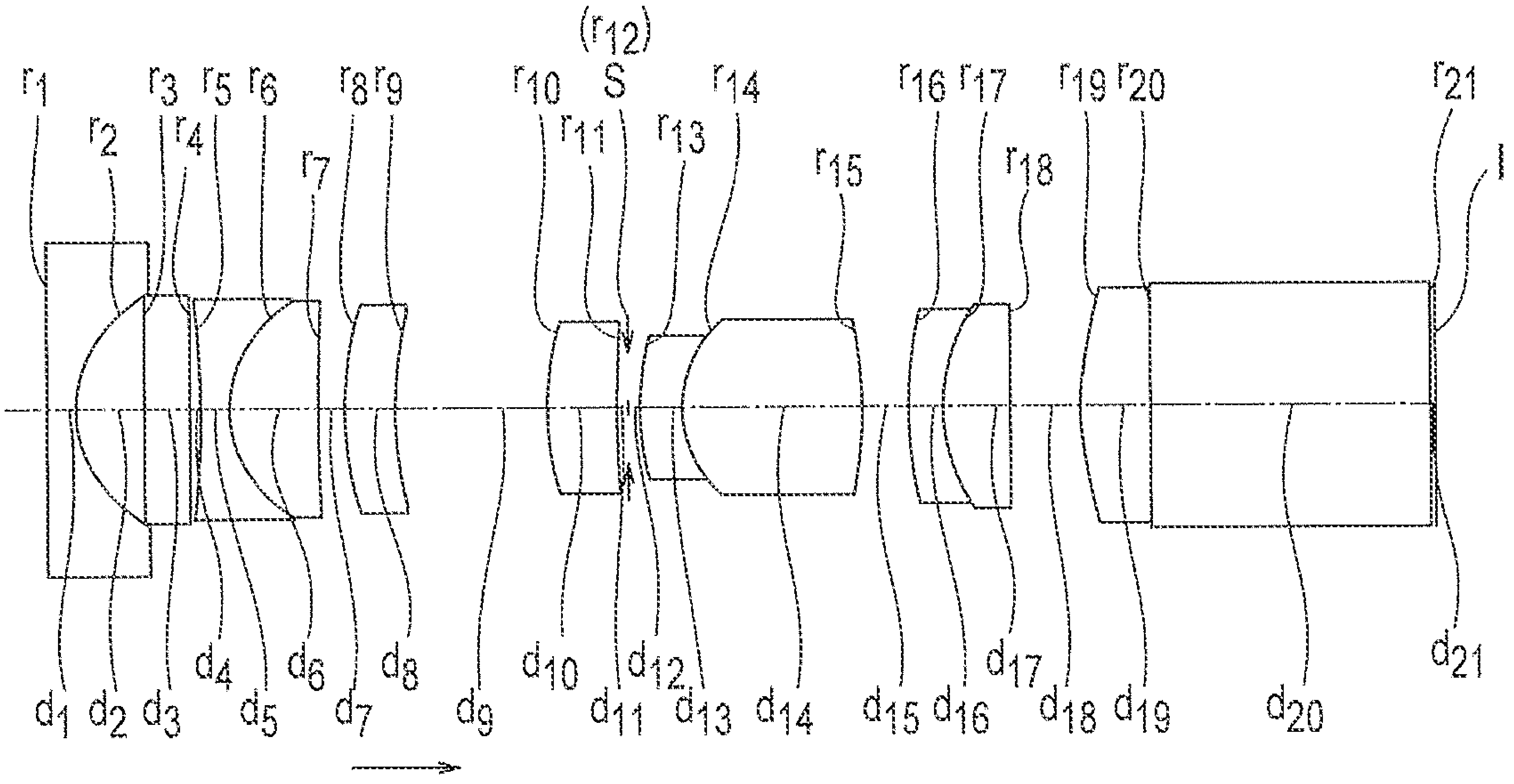


FIG. 10B

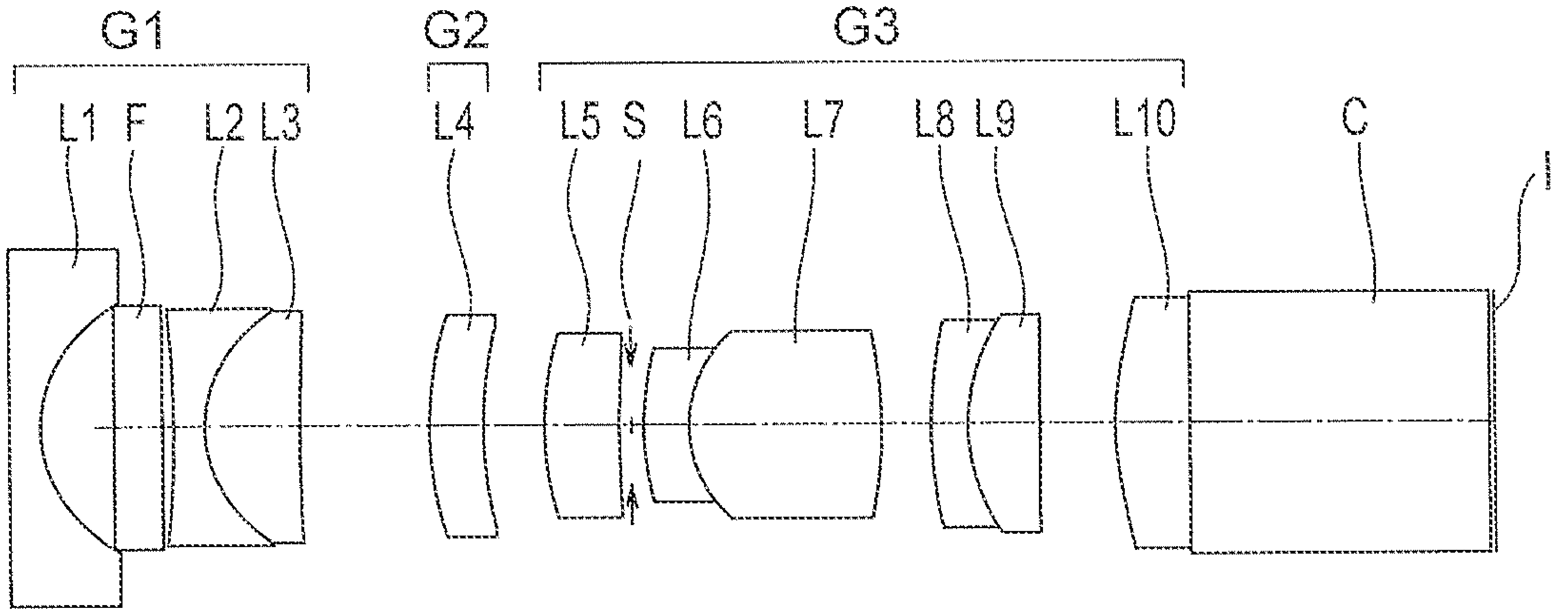


FIG. 11A

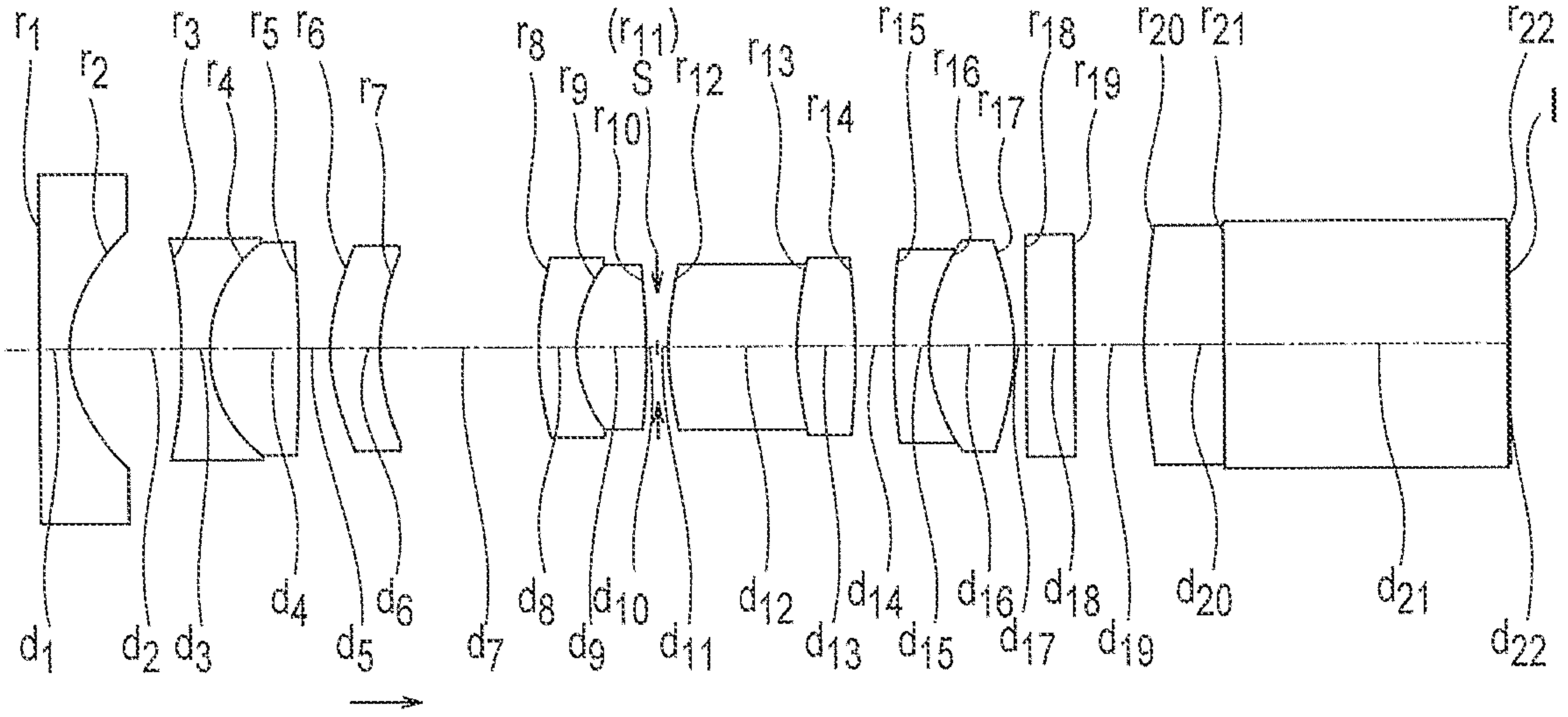


FIG. 11B

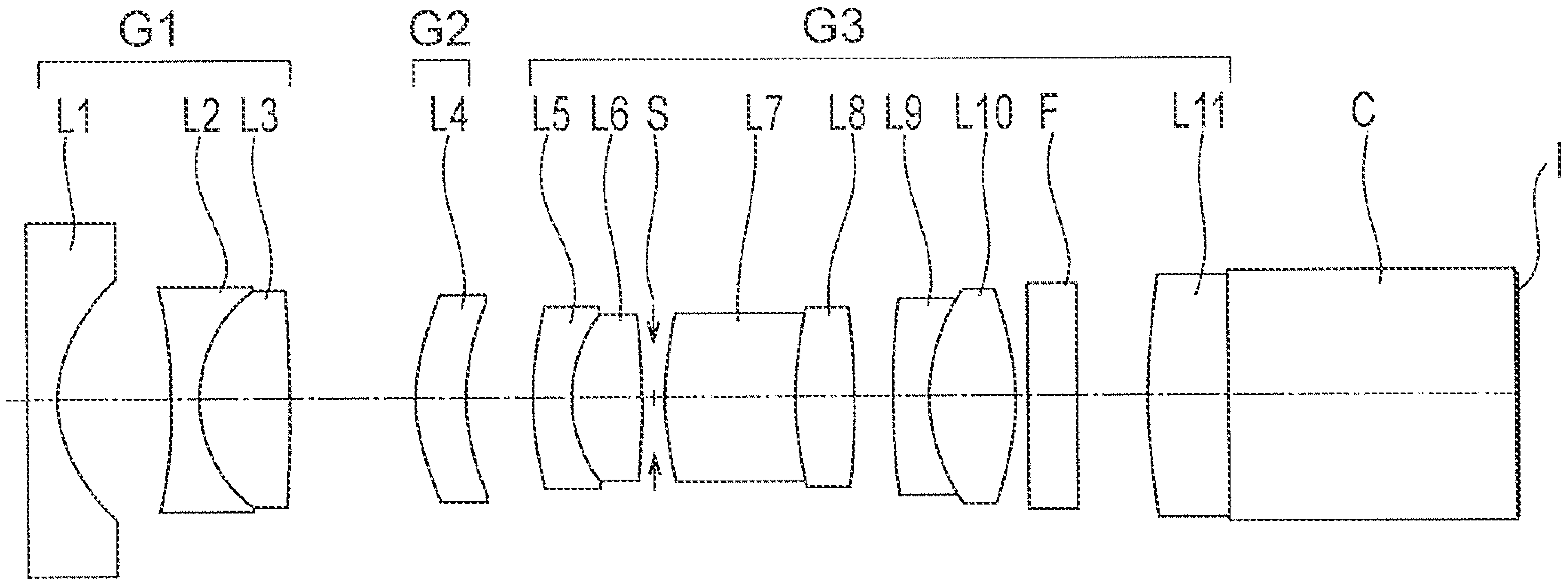


FIG. 12A

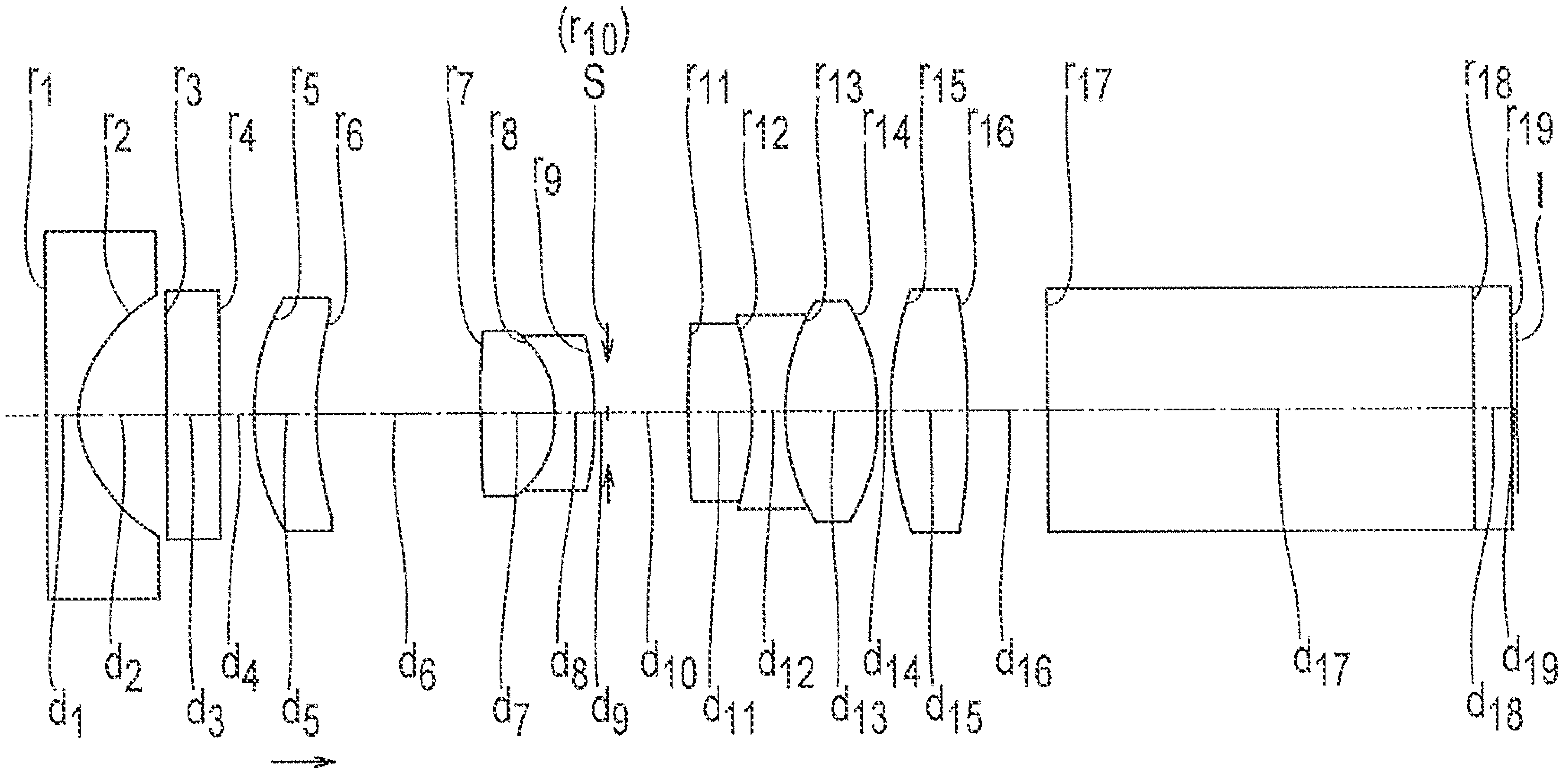


FIG. 12B

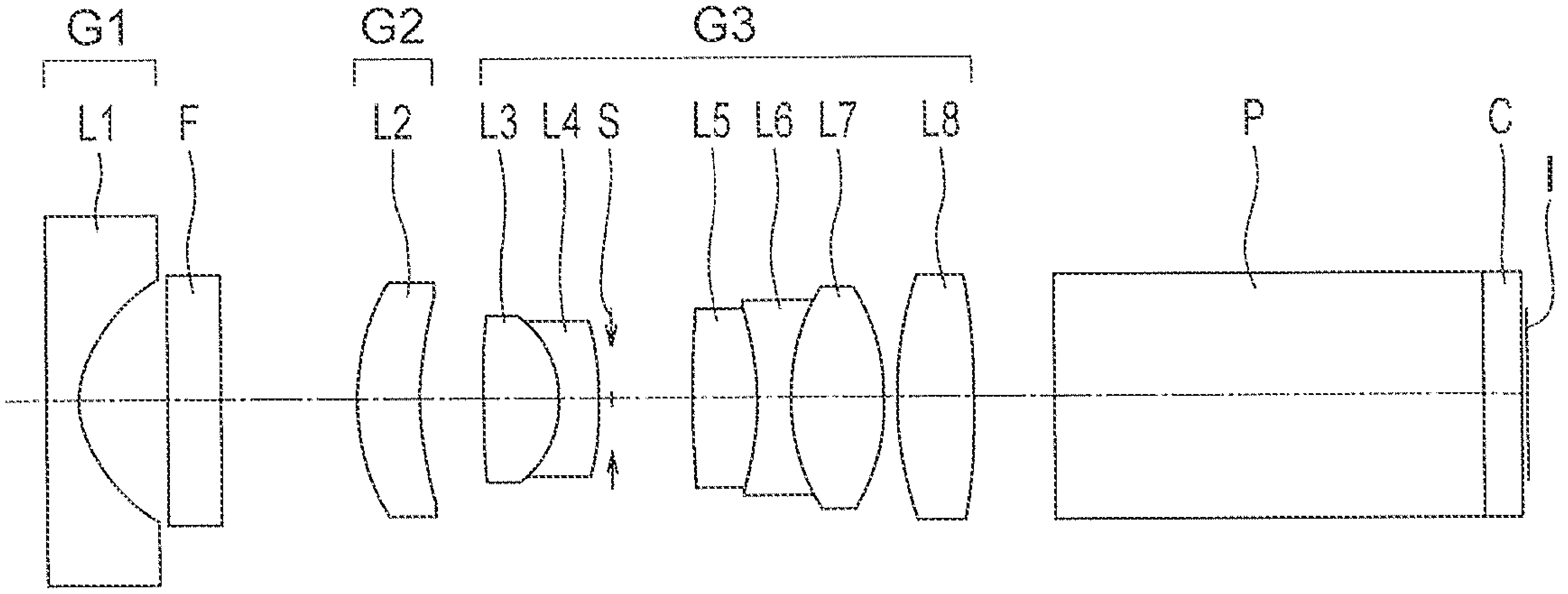


FIG. 13A

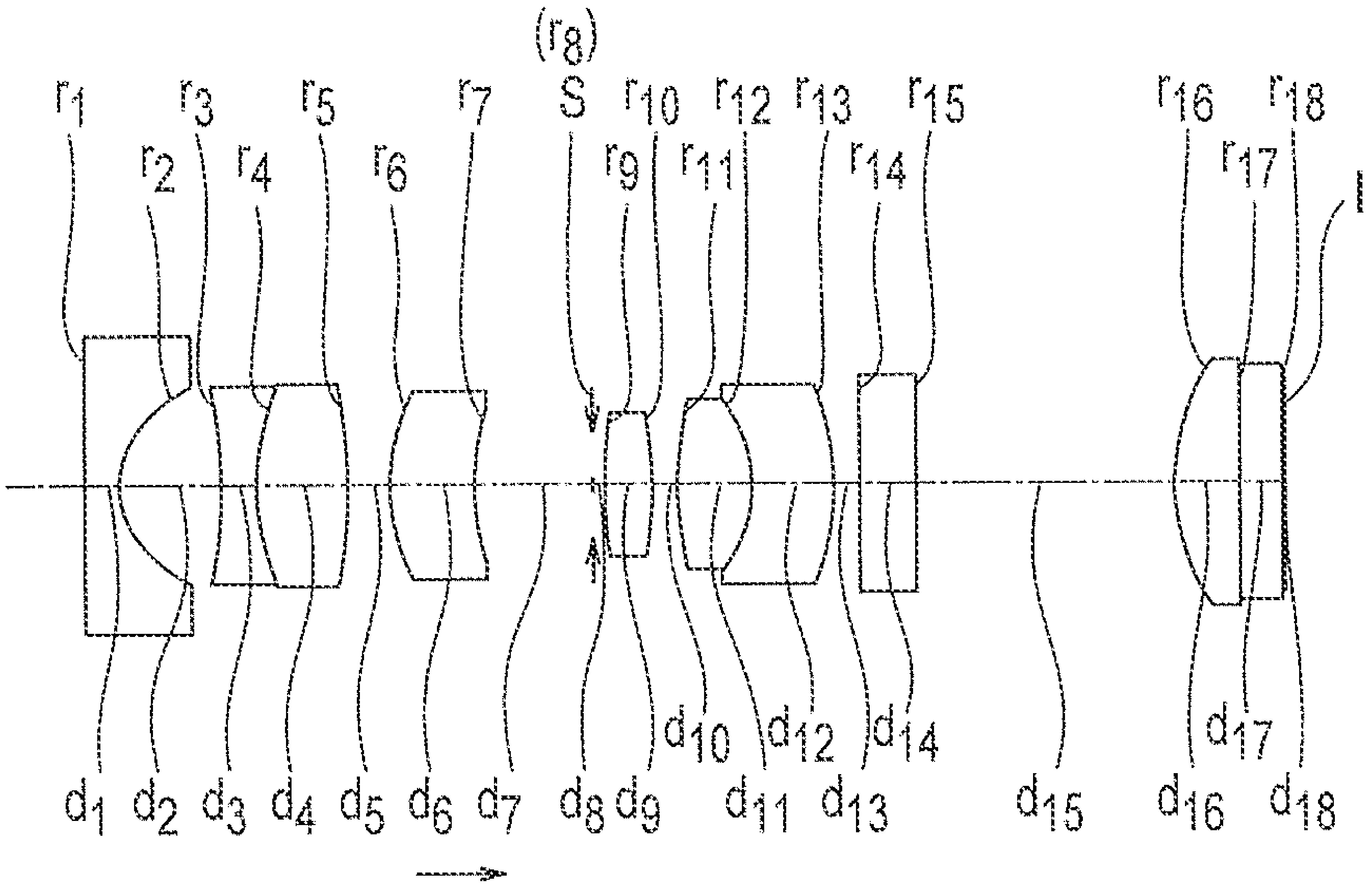
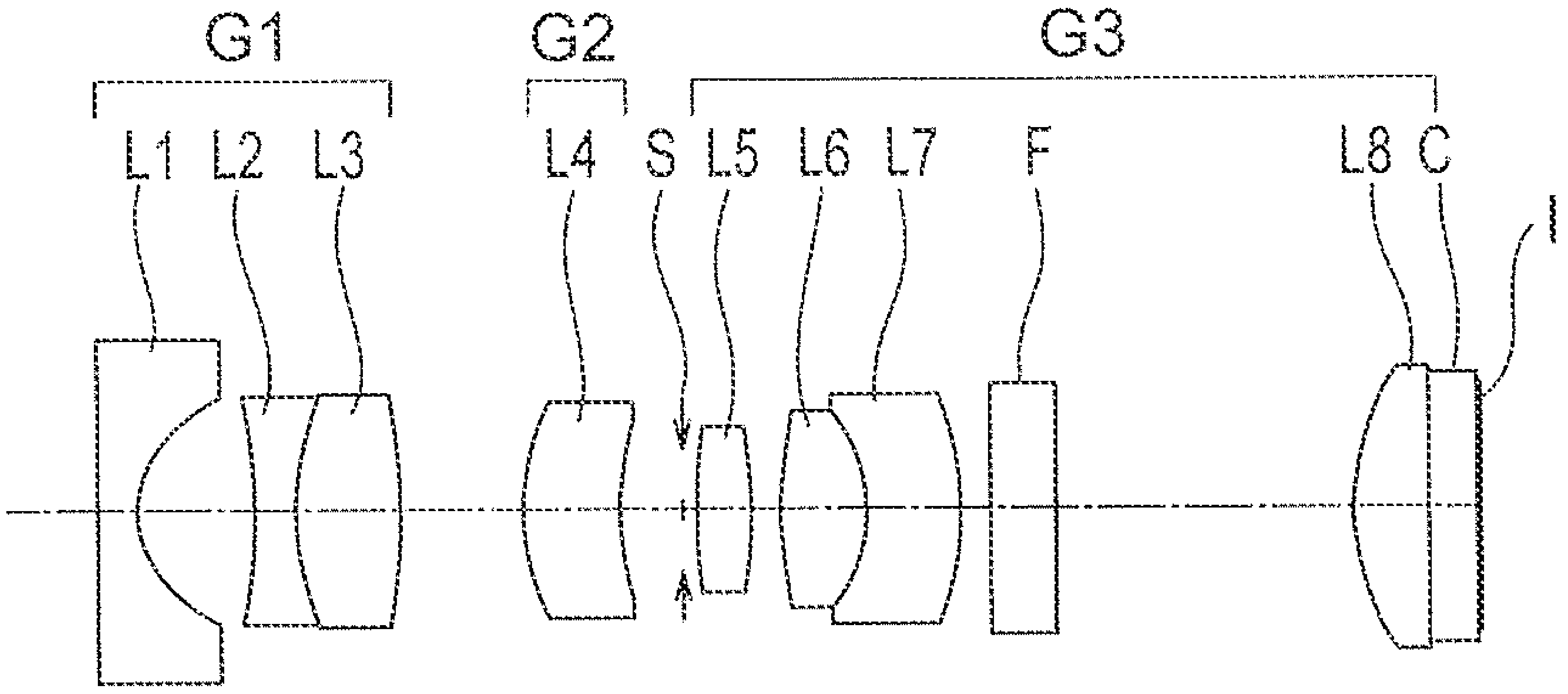
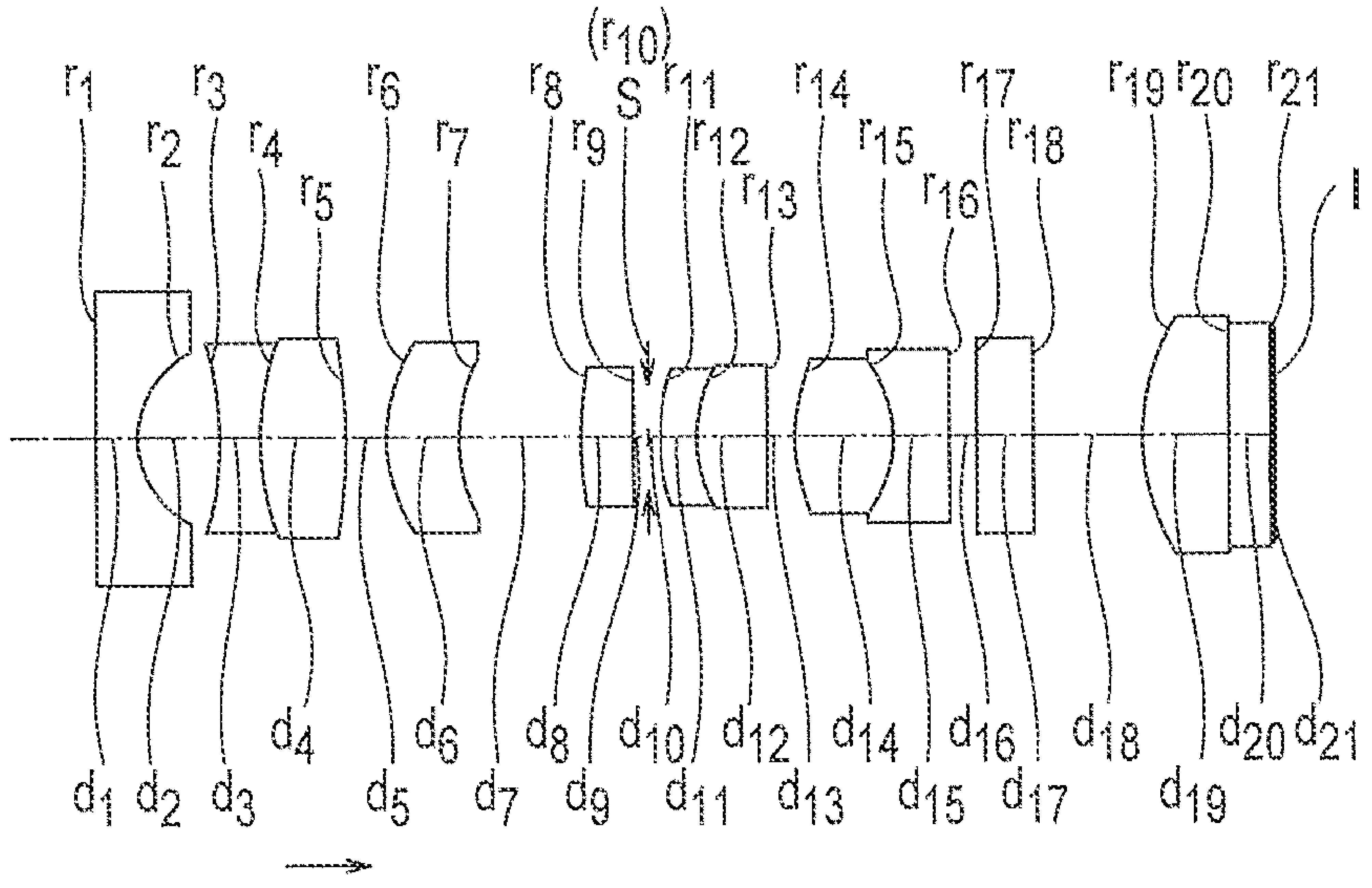


FIG. 13B



## FIG. 14A



## FIG. 14B

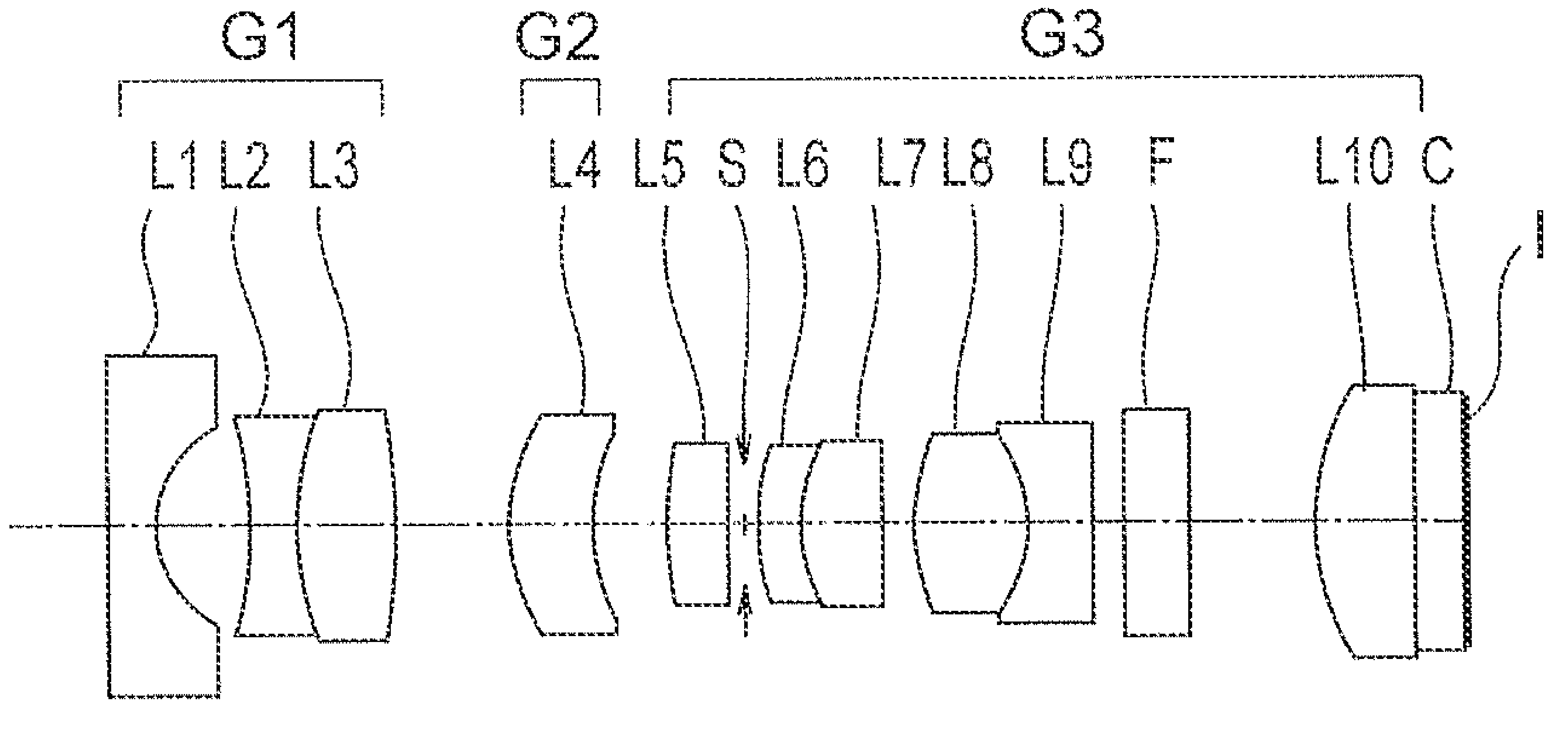


FIG. 15A

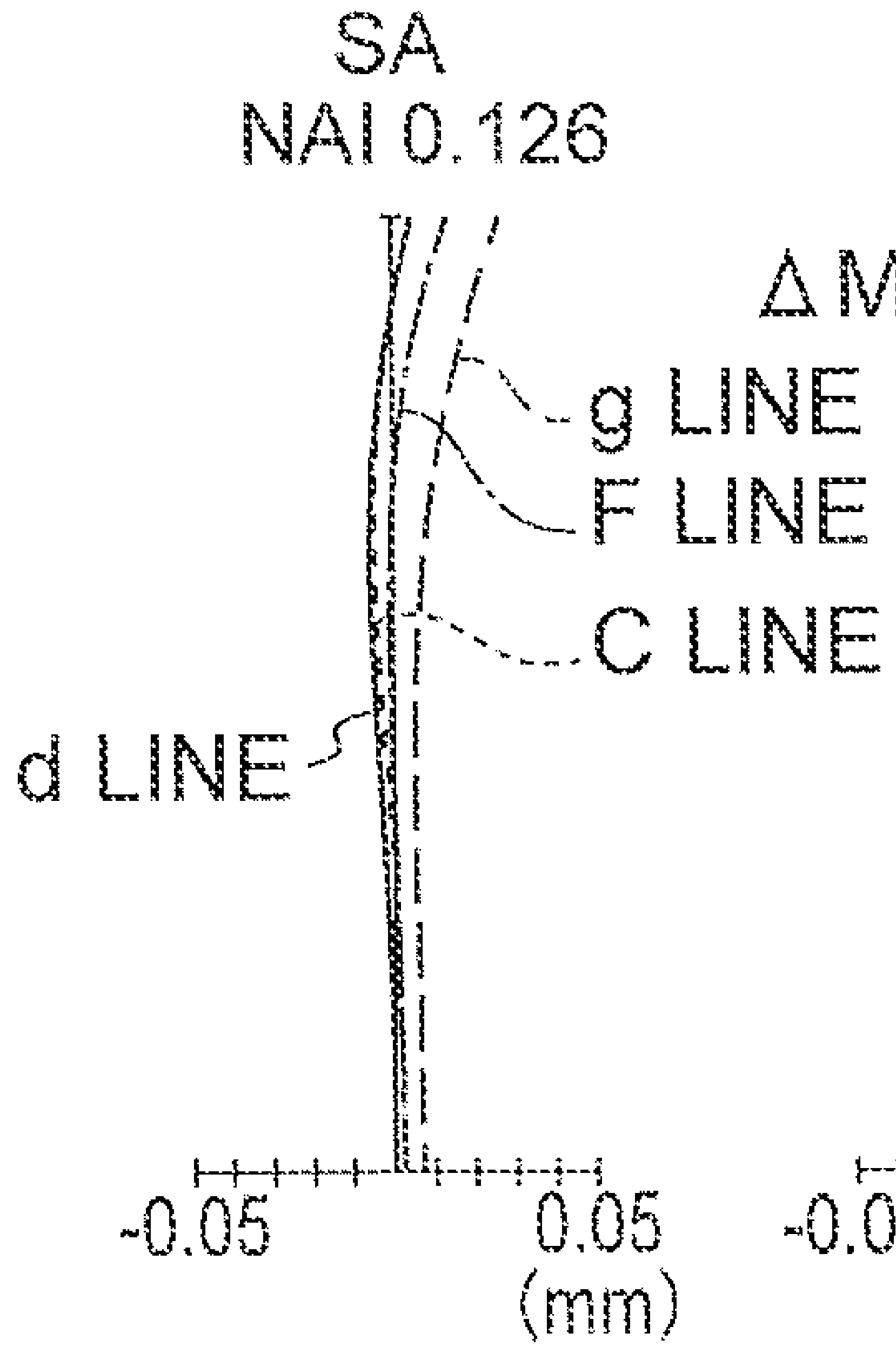


FIG. 15B

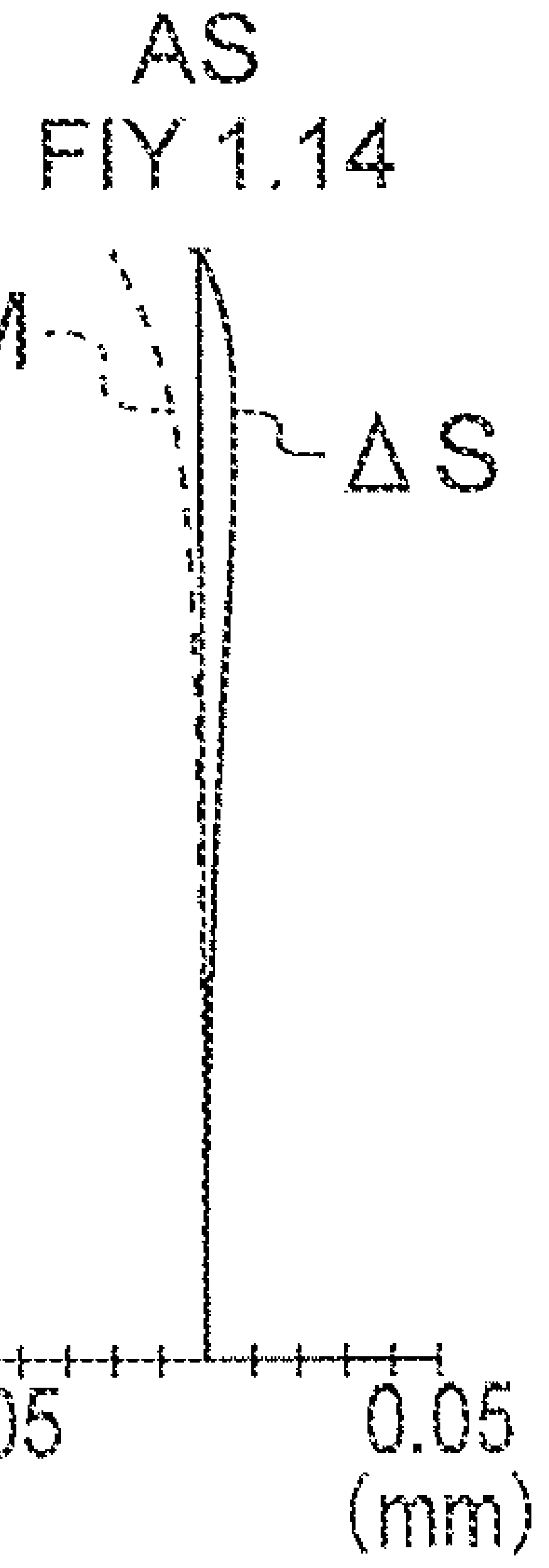


FIG. 15C

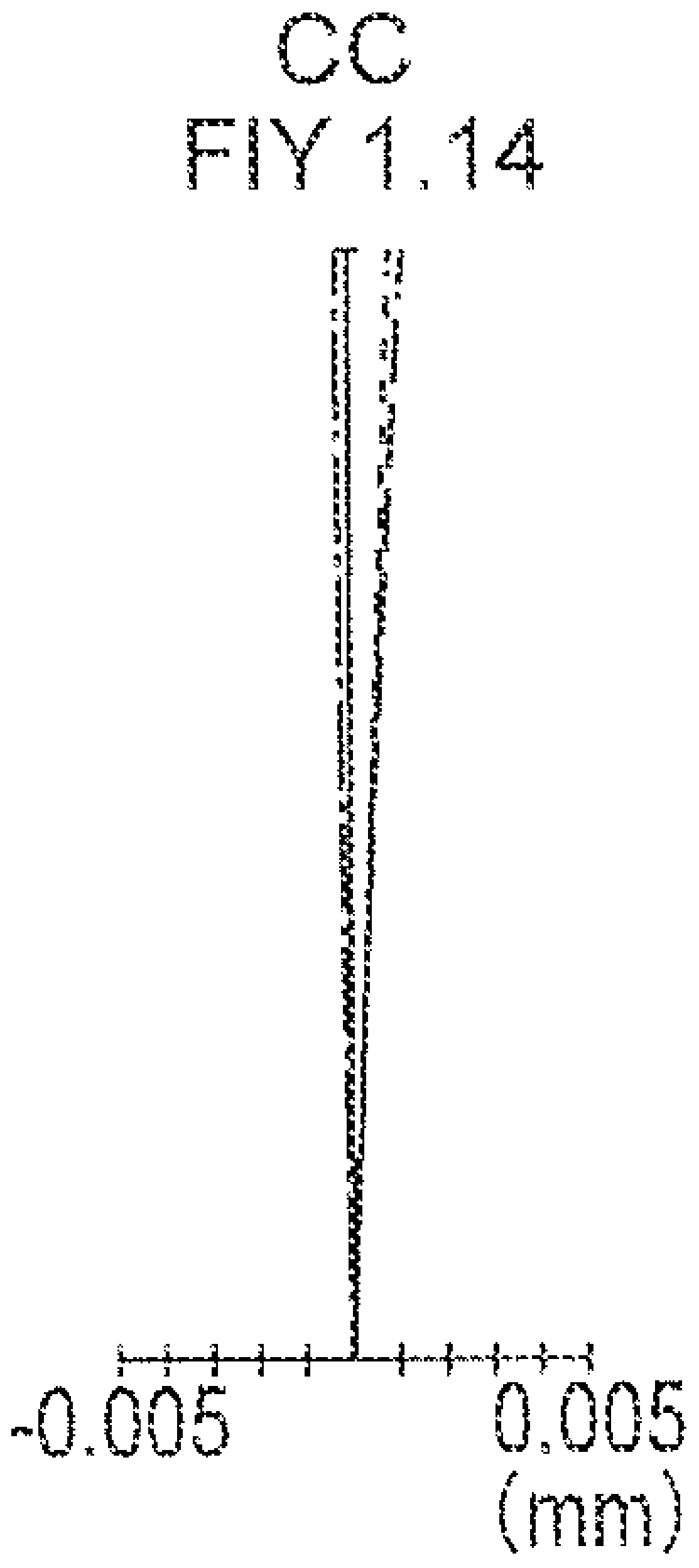


FIG. 15D

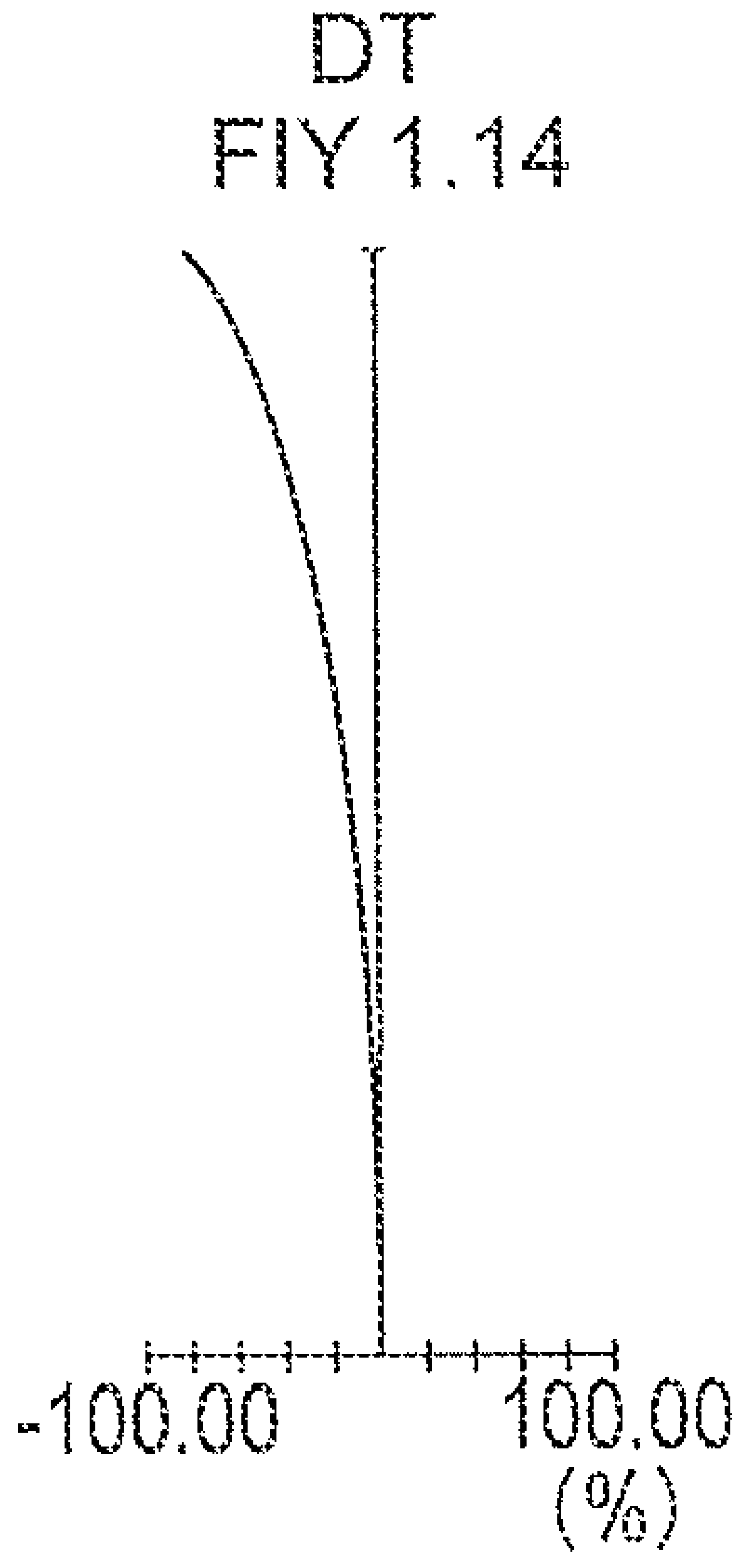


FIG. 15E

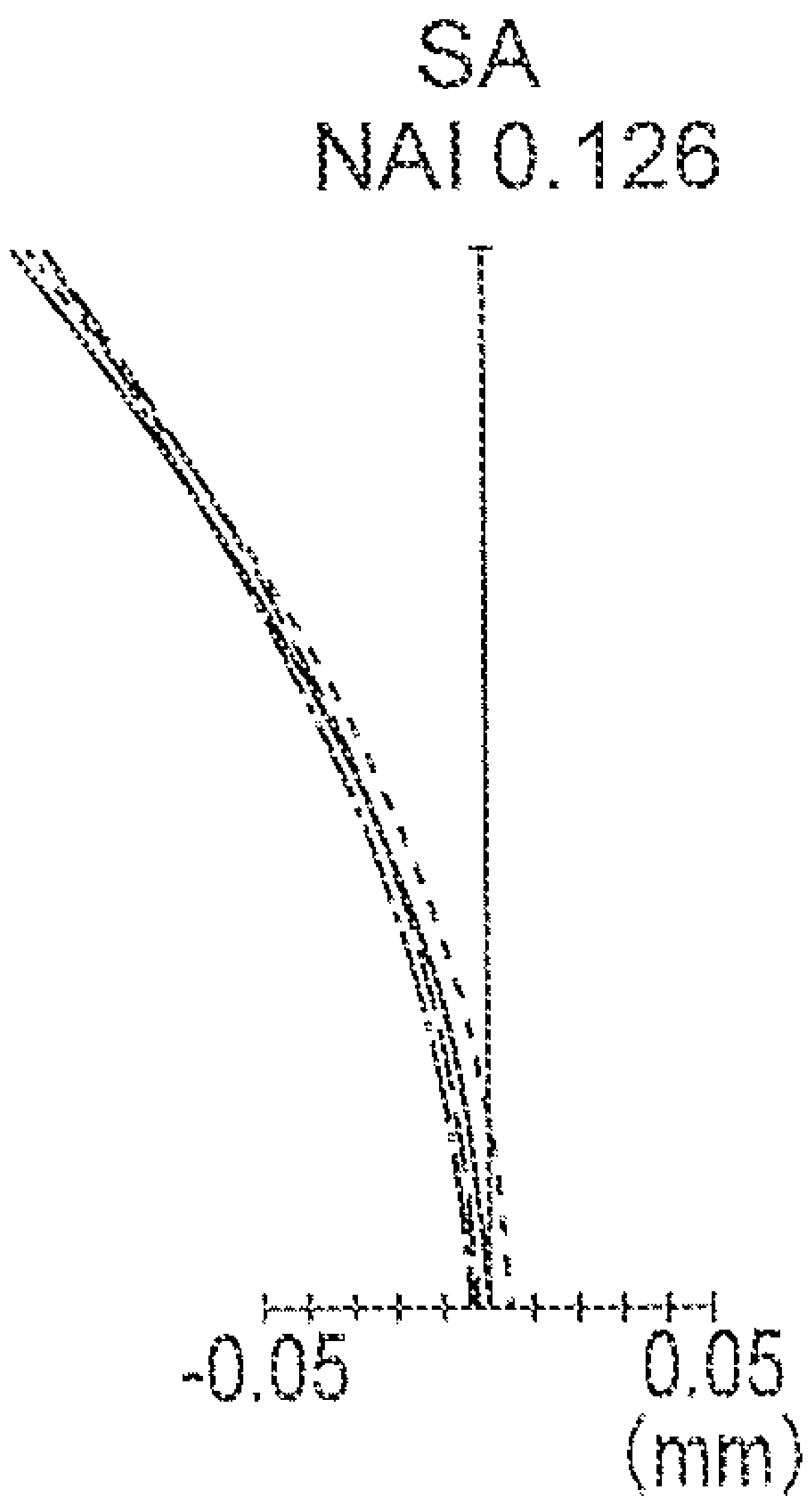


FIG. 15F

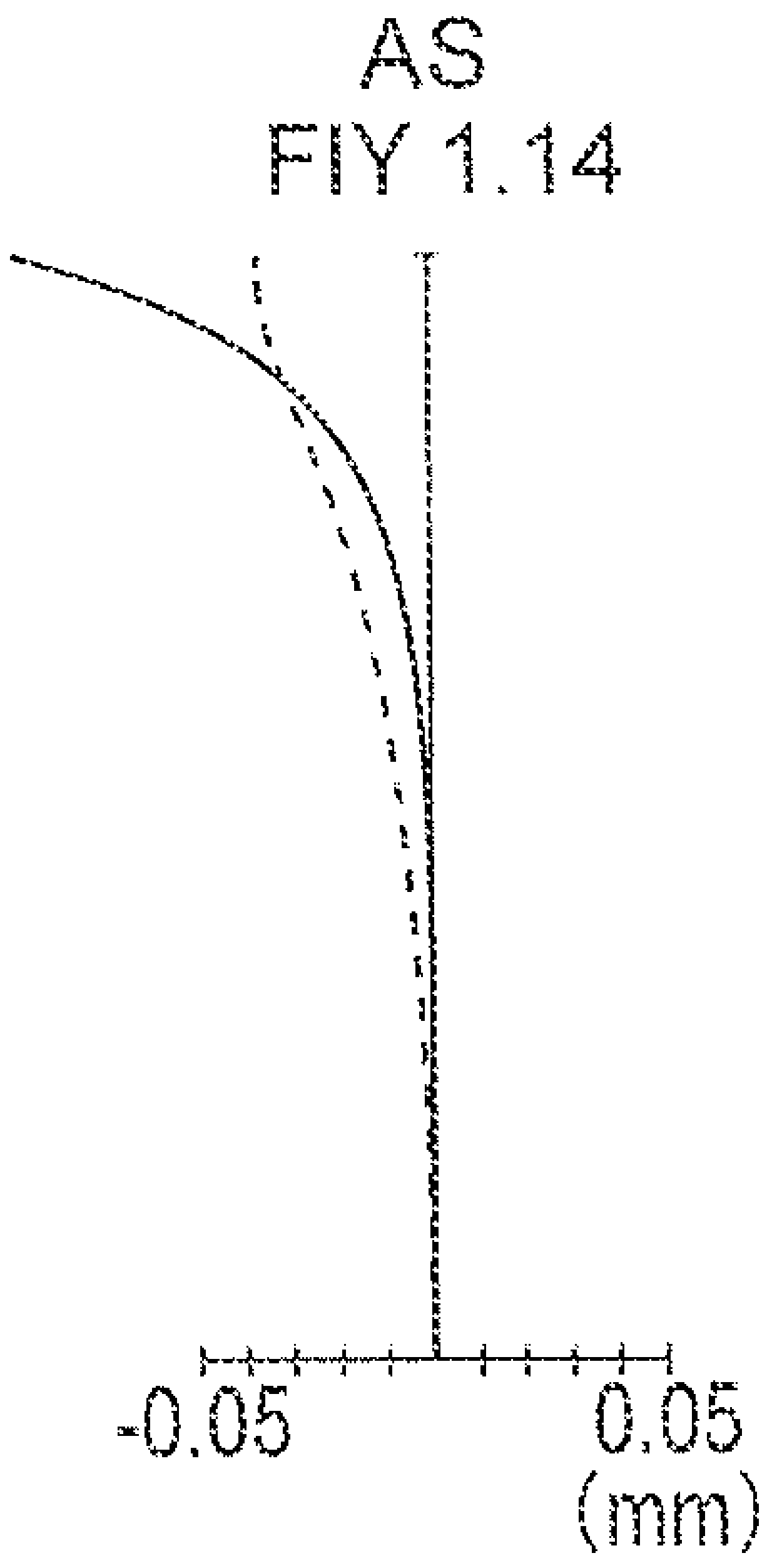


FIG. 15G

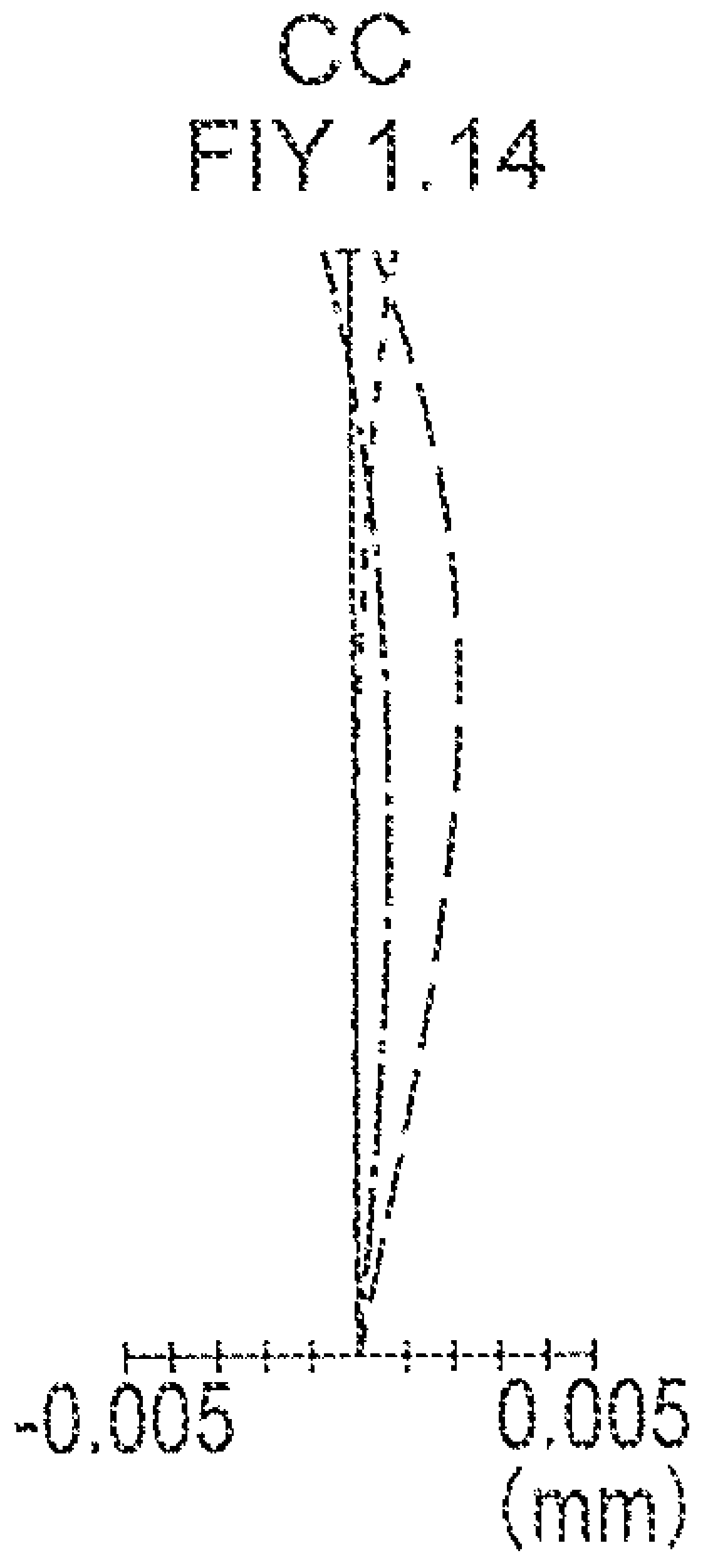
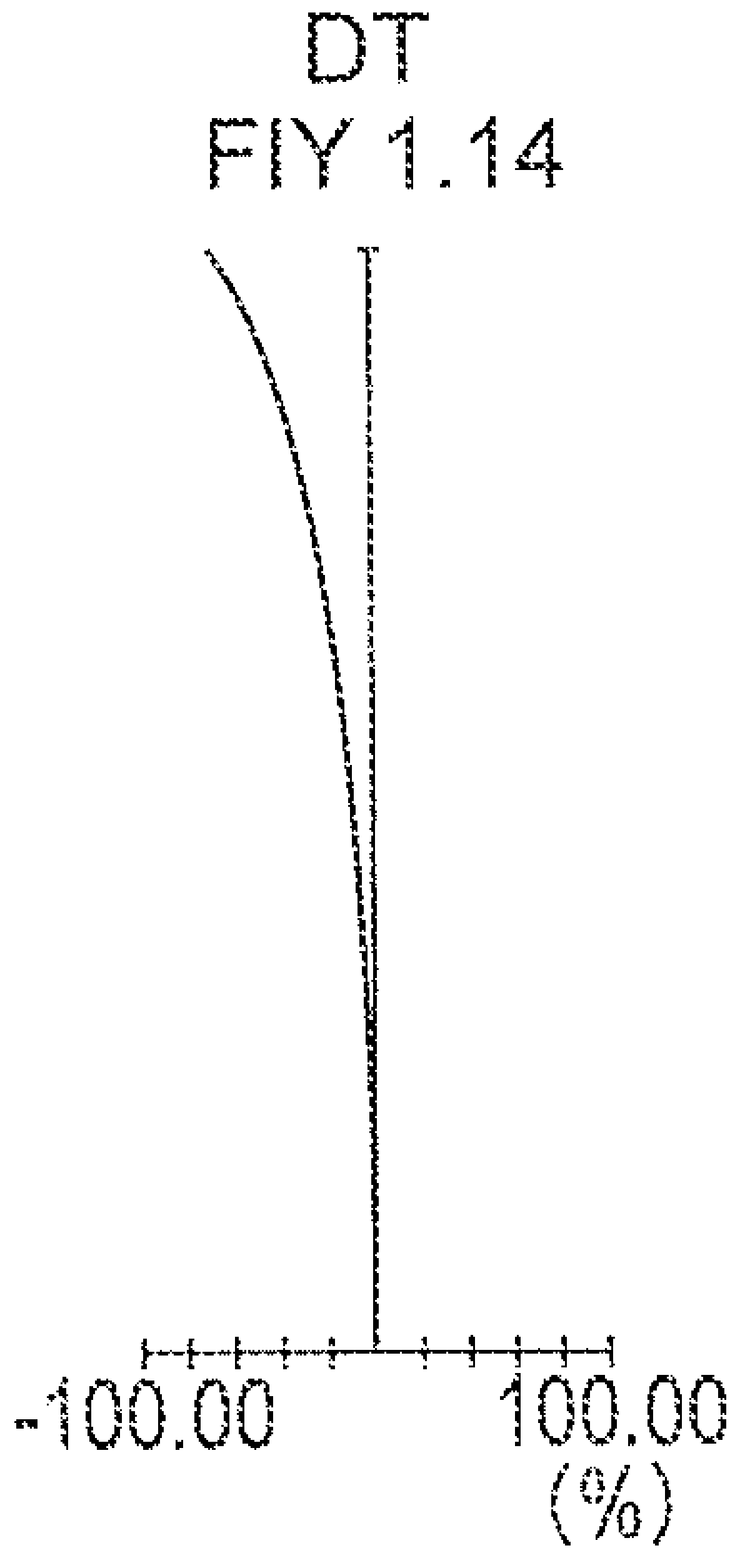


FIG. 15H



435.84 - - - - - -
486.13 -·-·-·-·-
587.56 ————
656.27 - - - - - - - -

FIG. 16A

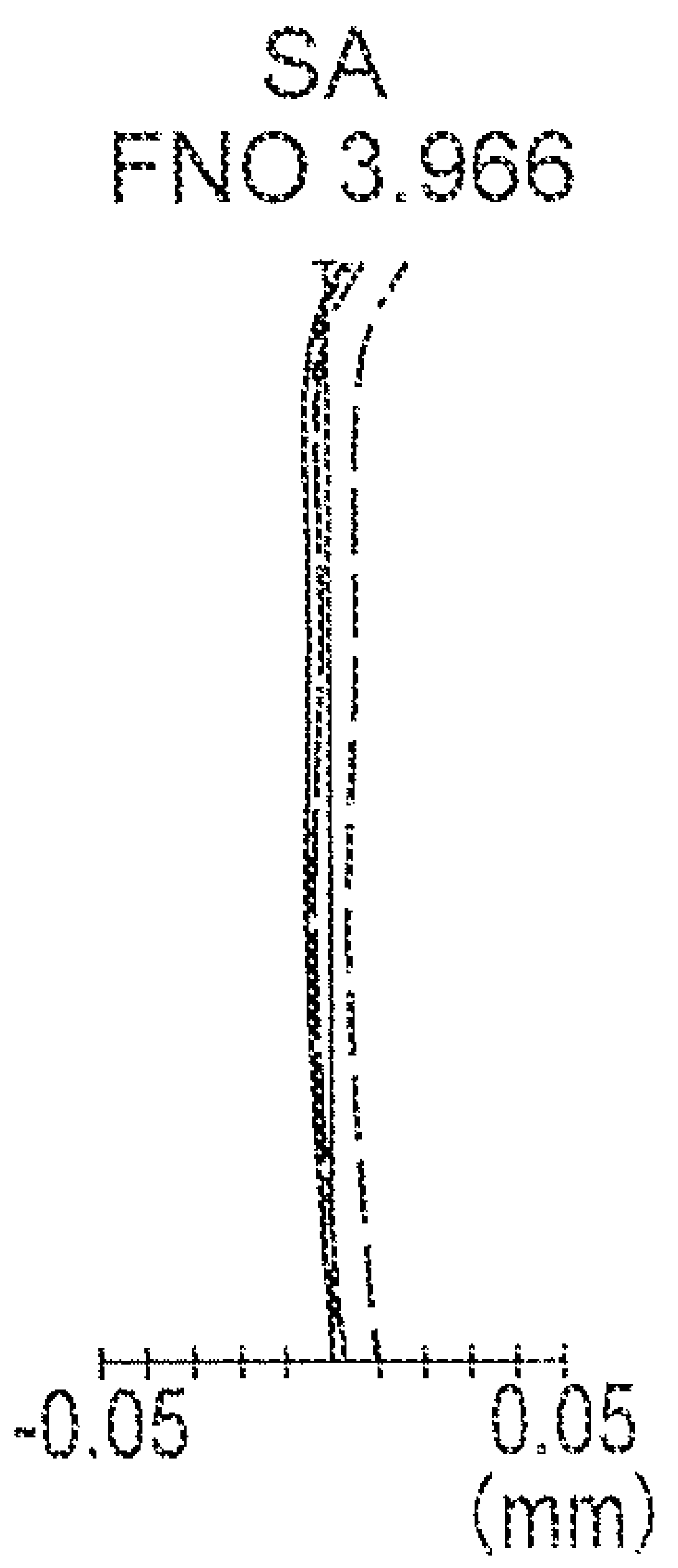


FIG. 16B

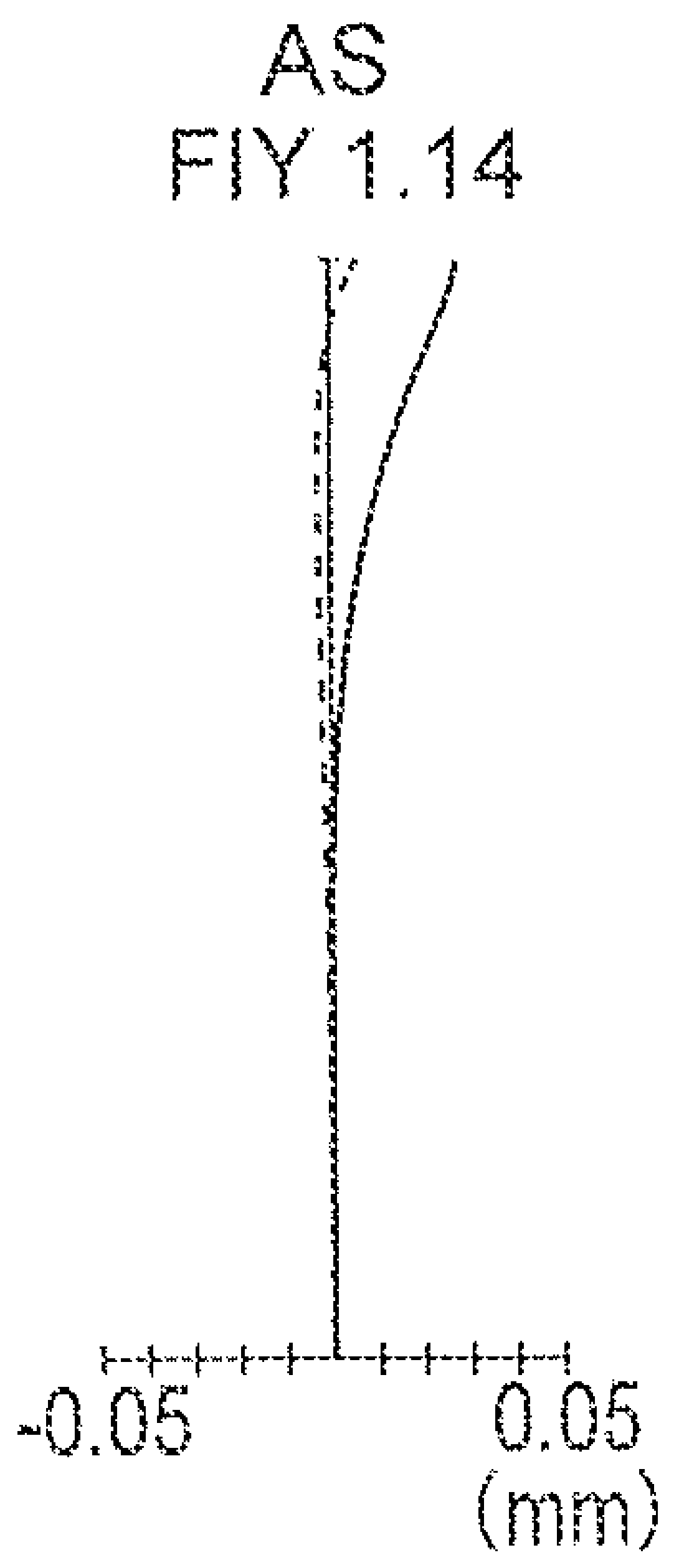


FIG. 16C

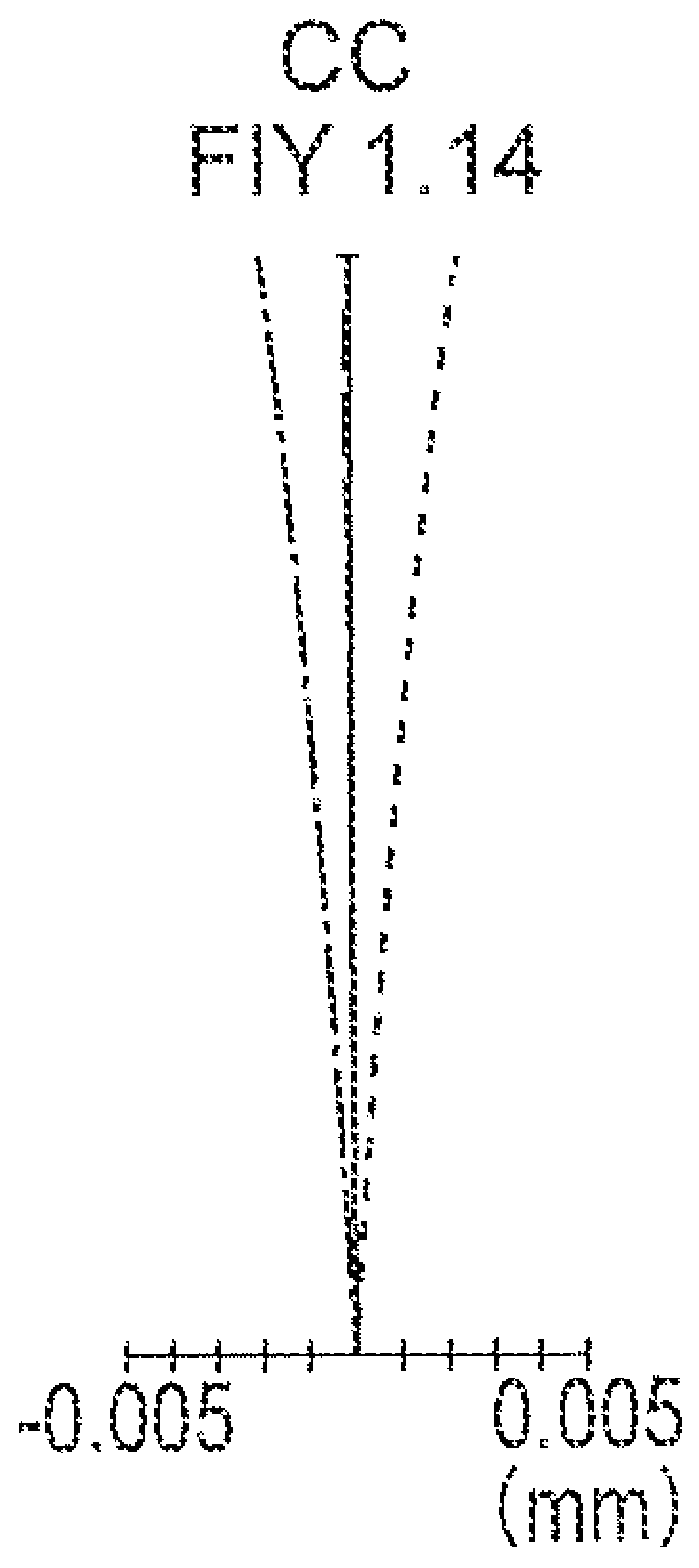


FIG. 16D

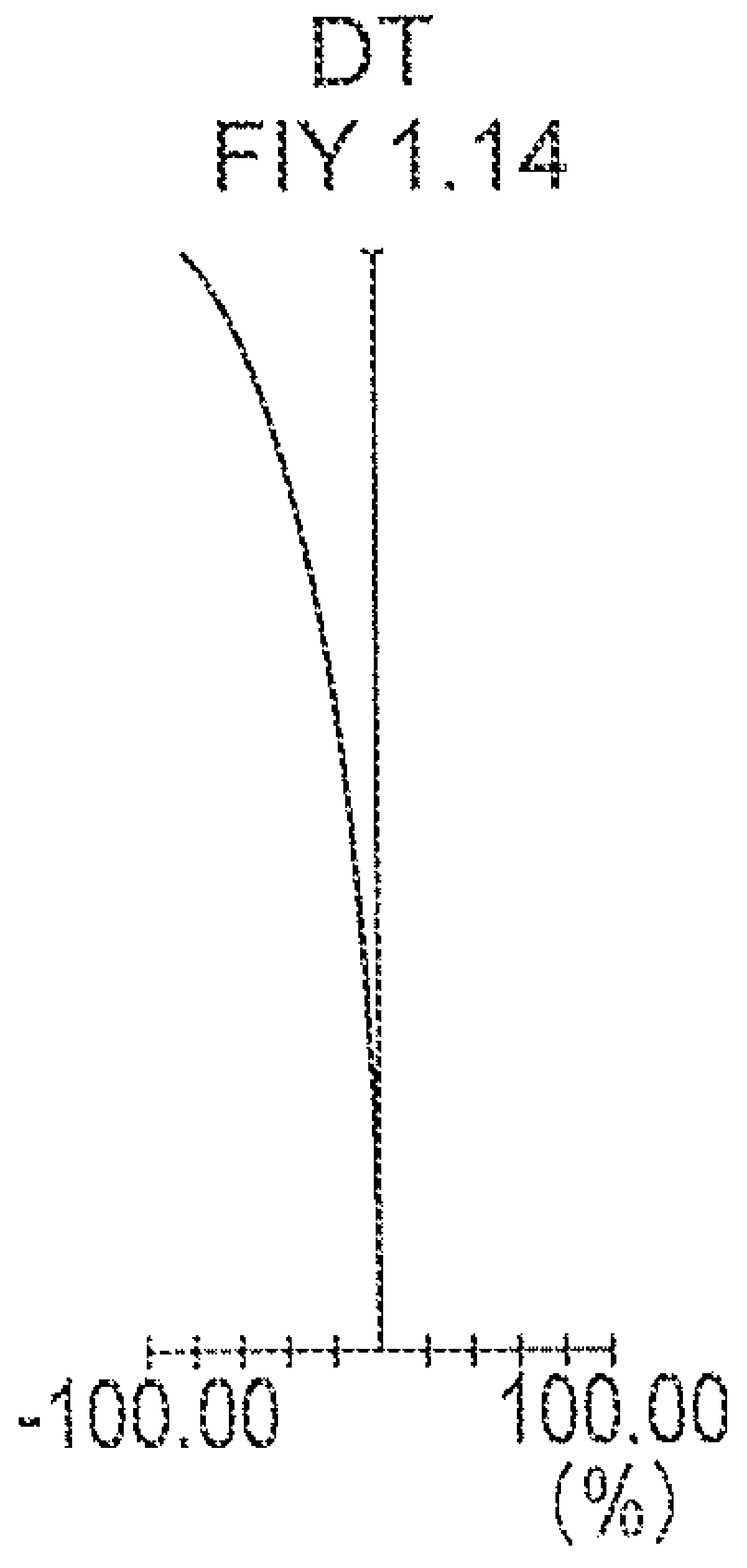


FIG. 16E

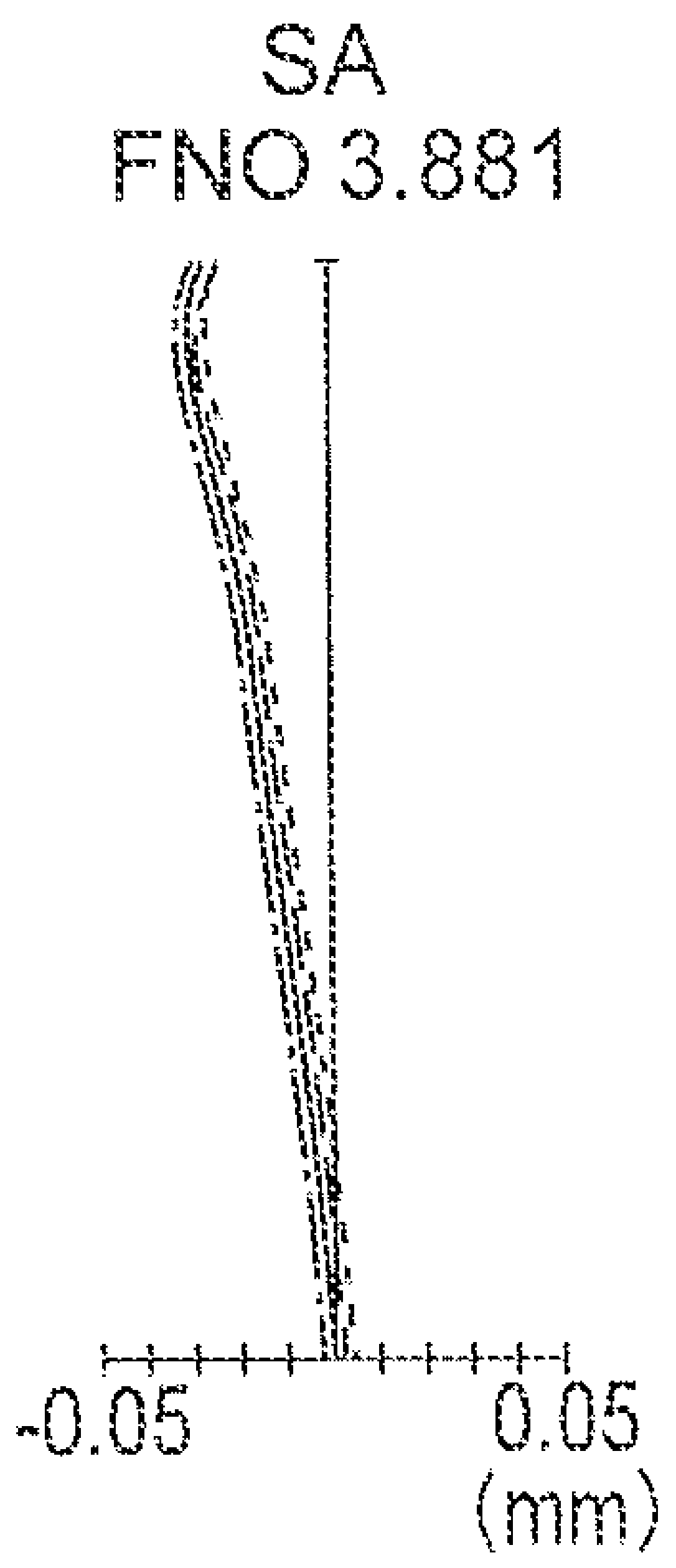


FIG. 16F

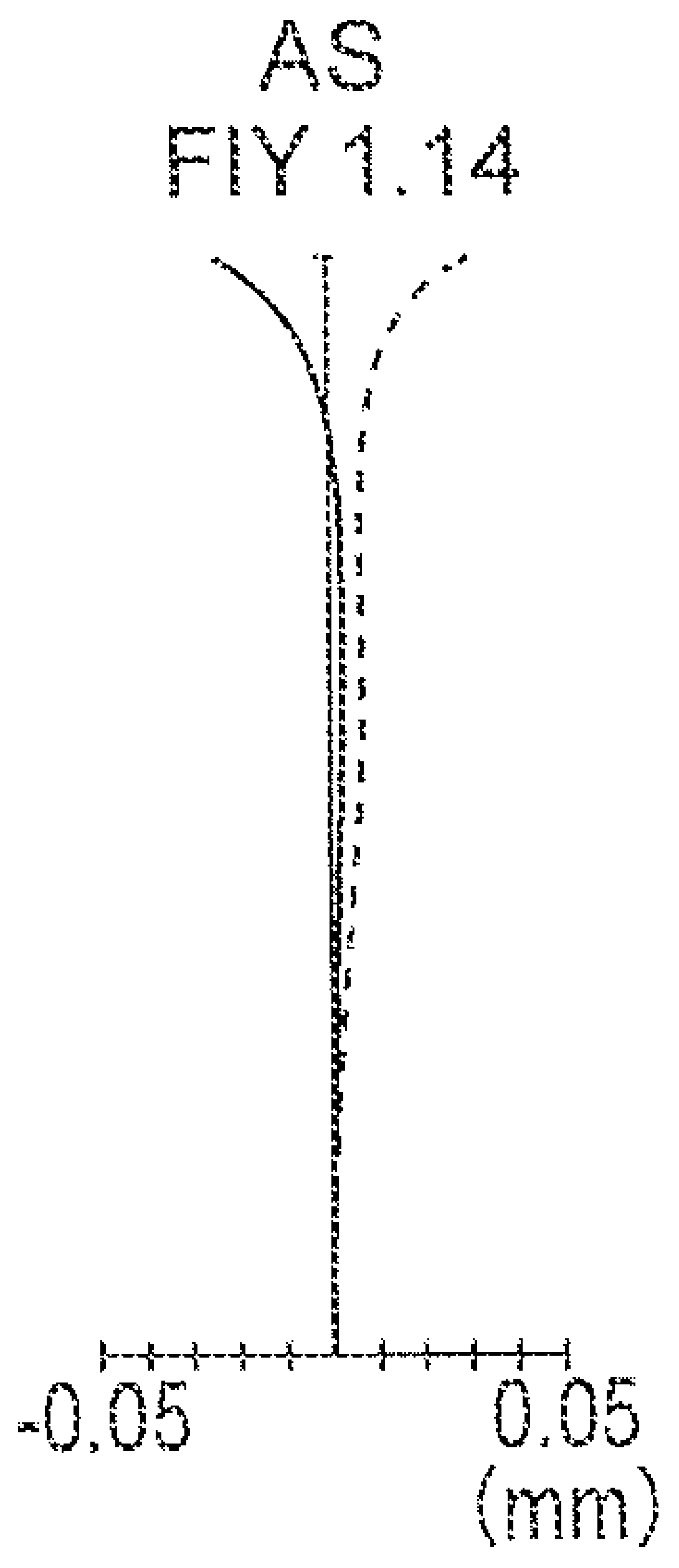


FIG. 16G

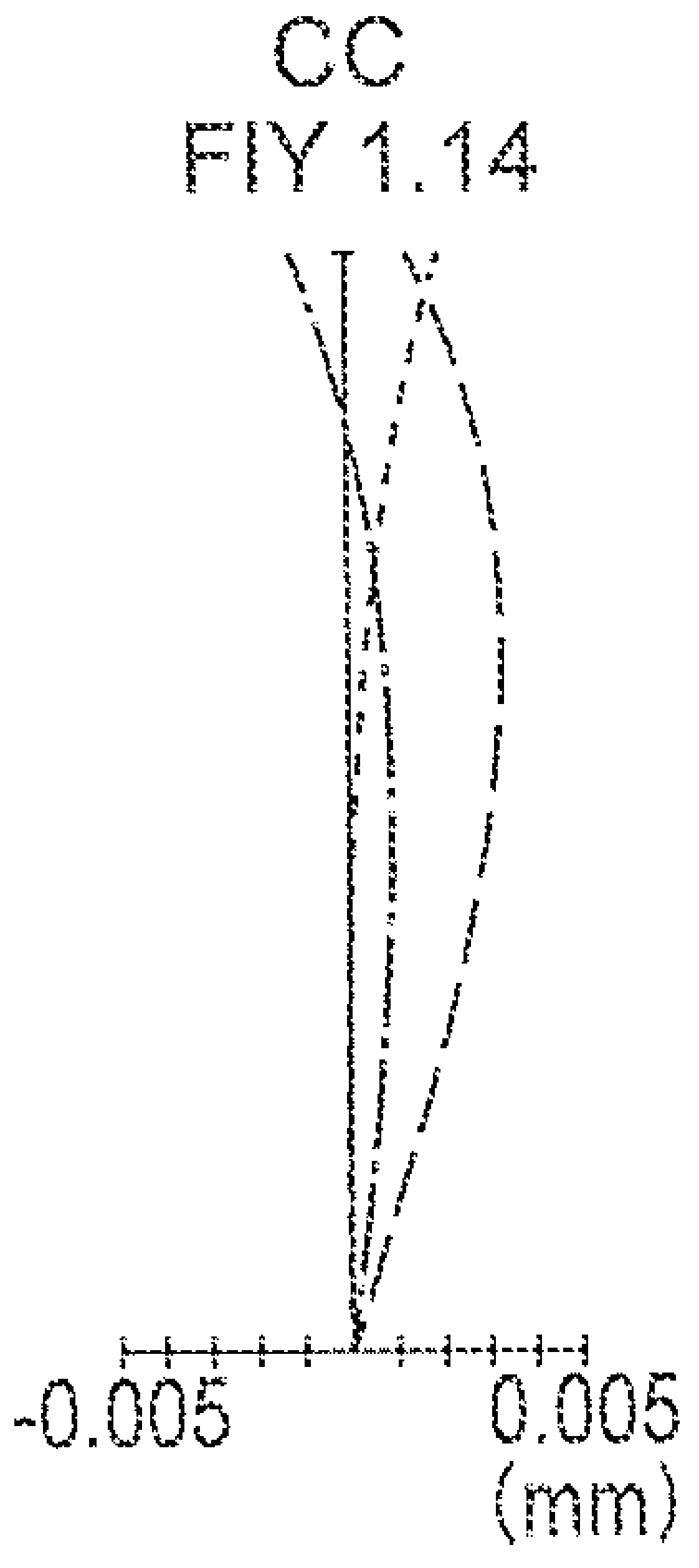


FIG. 16H

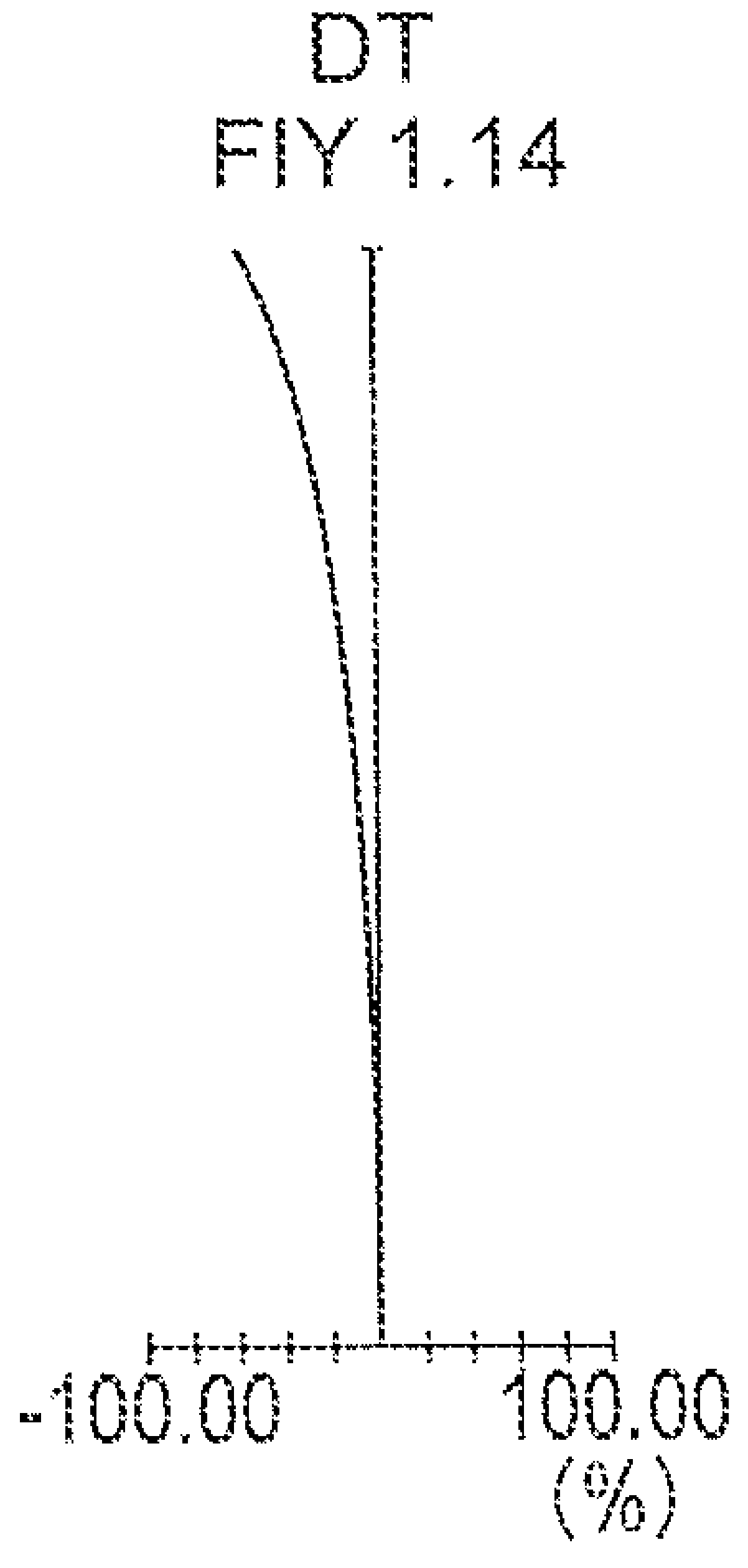


FIG. 17A

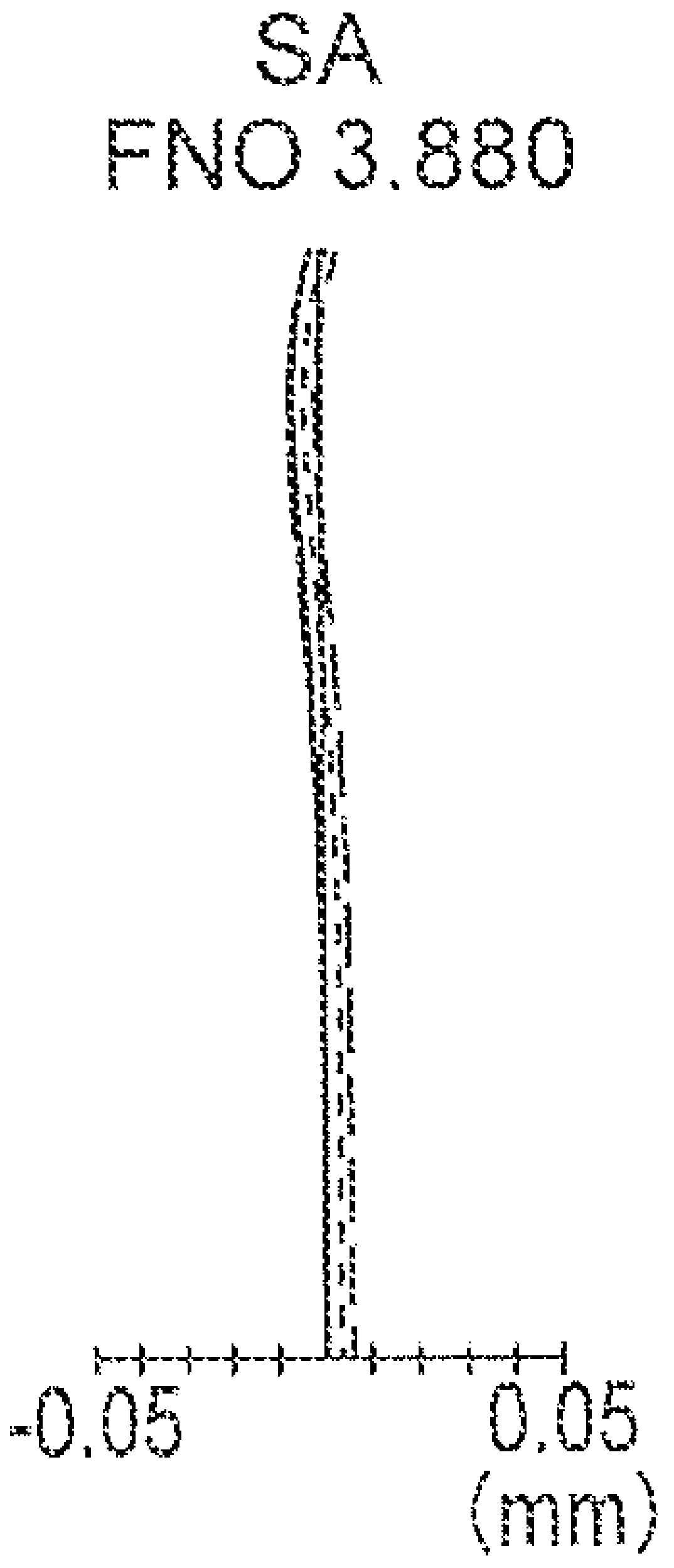


FIG. 17B

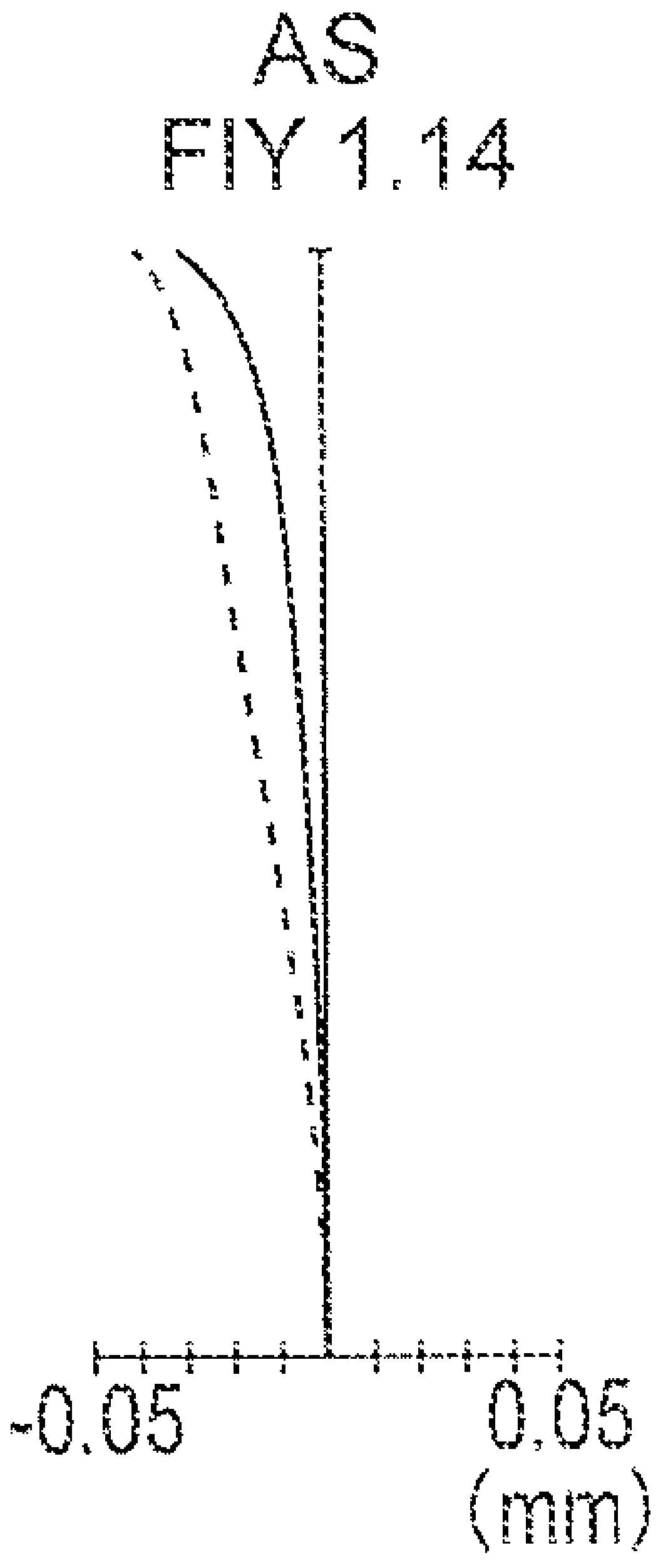


FIG. 17C

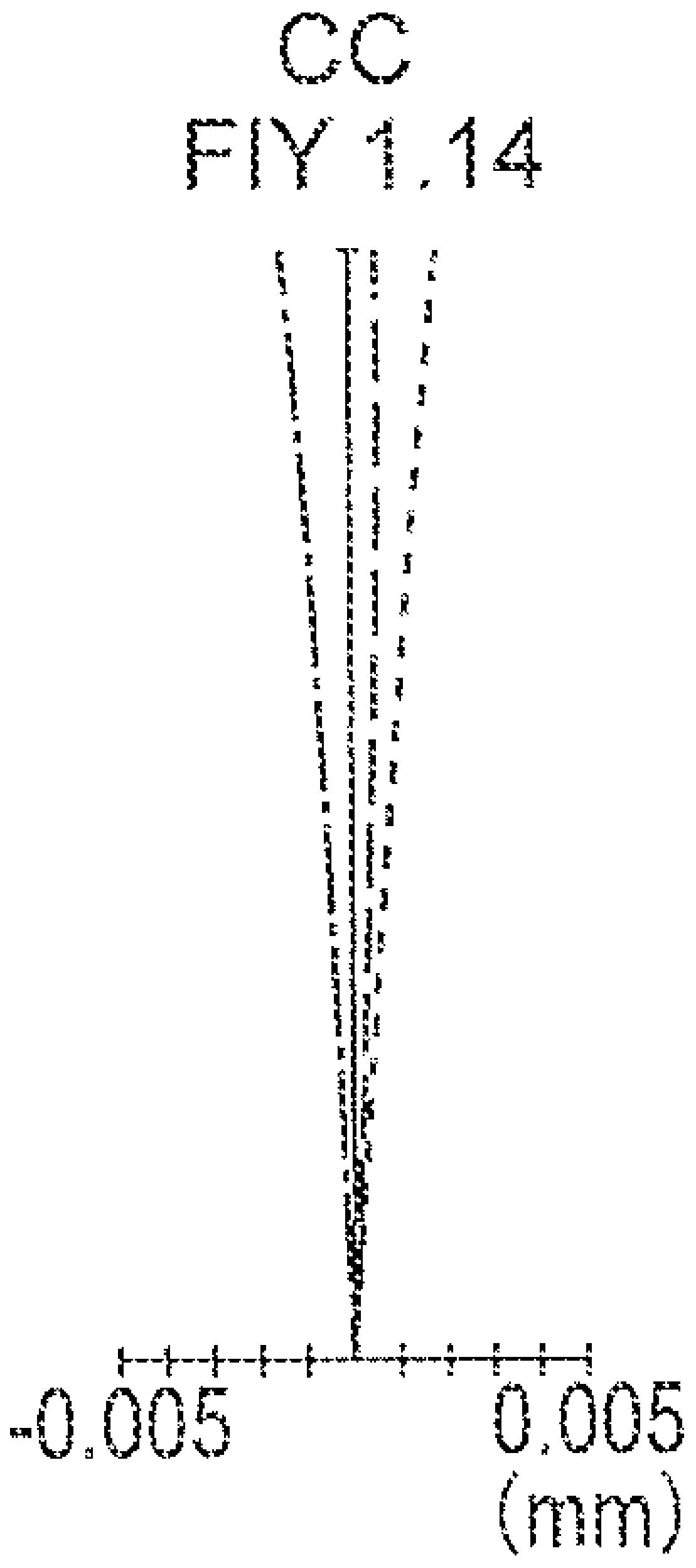


FIG. 17D

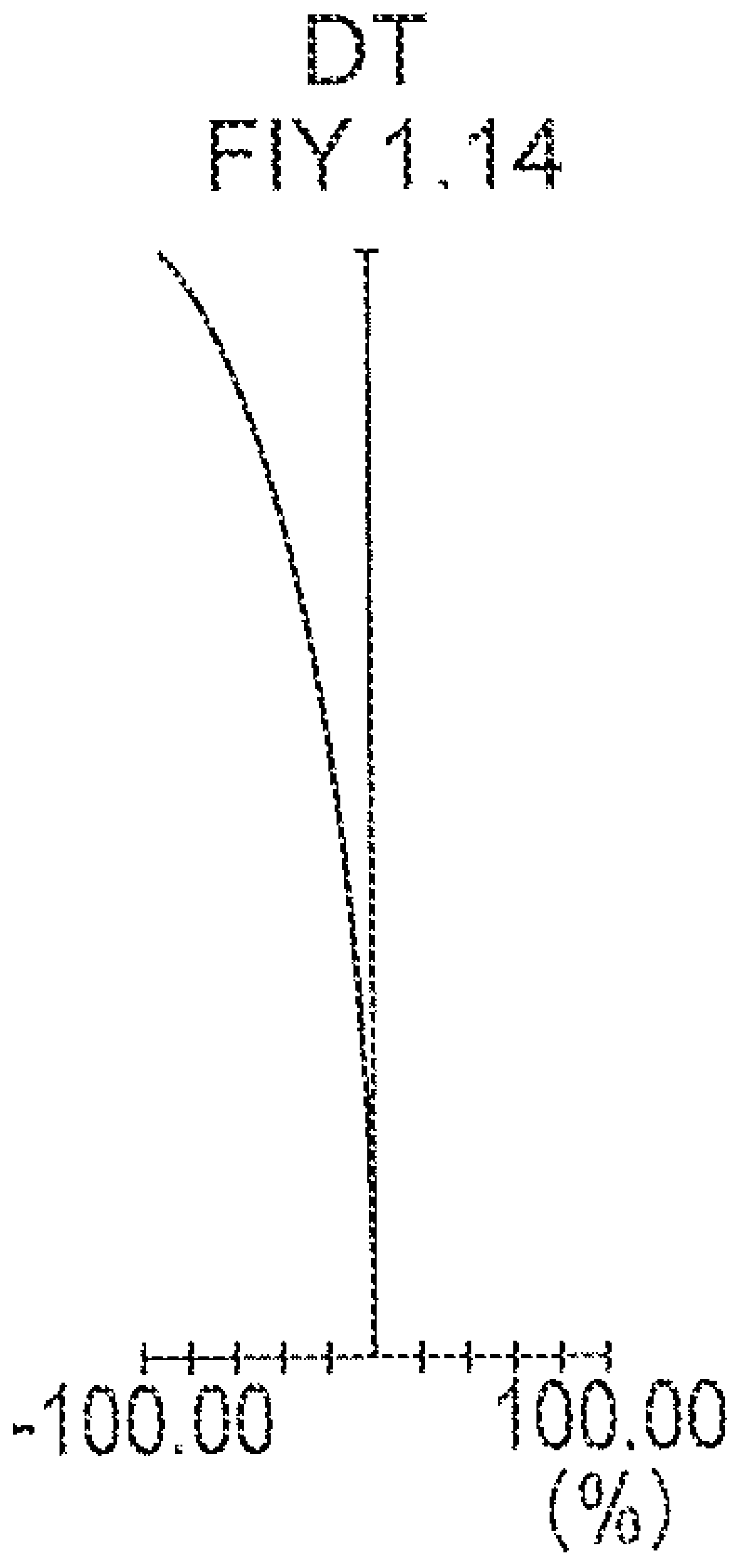


FIG. 17E

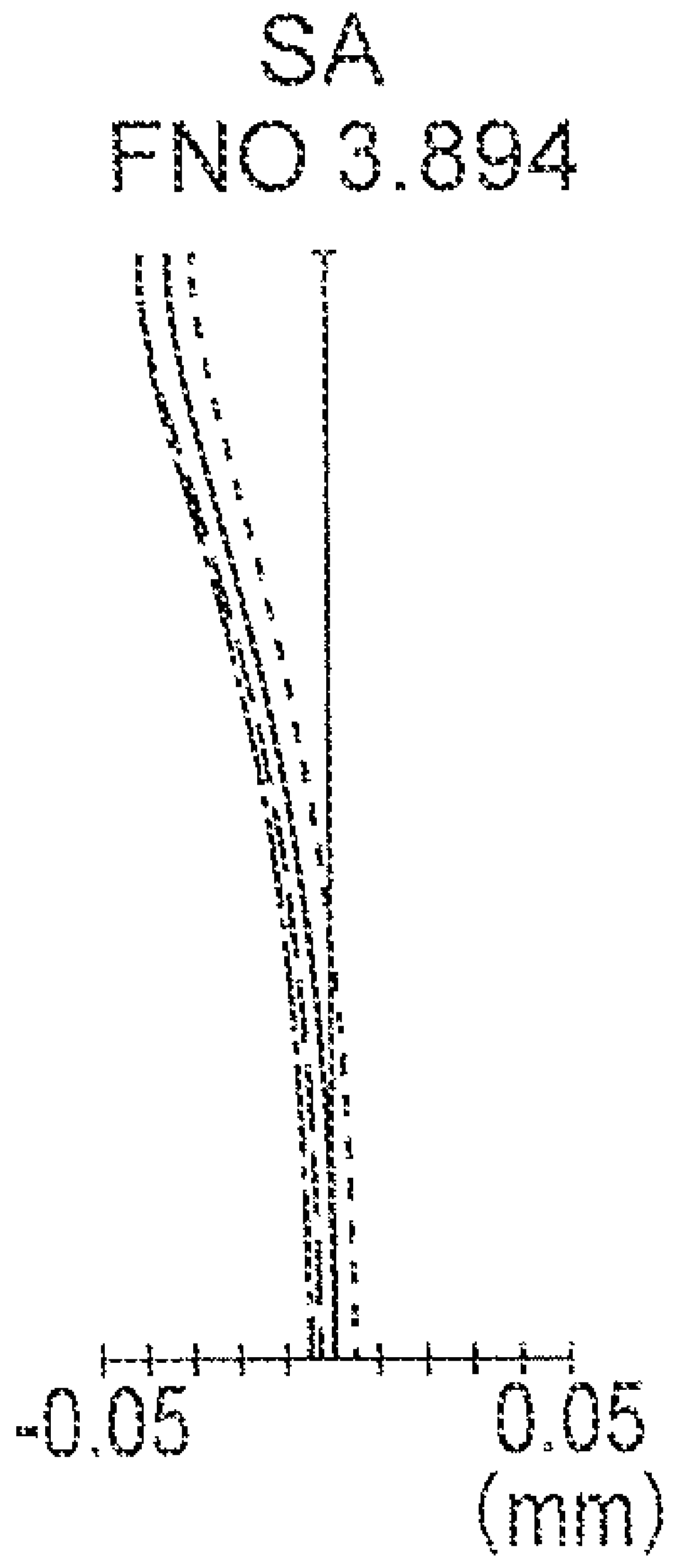


FIG. 17F

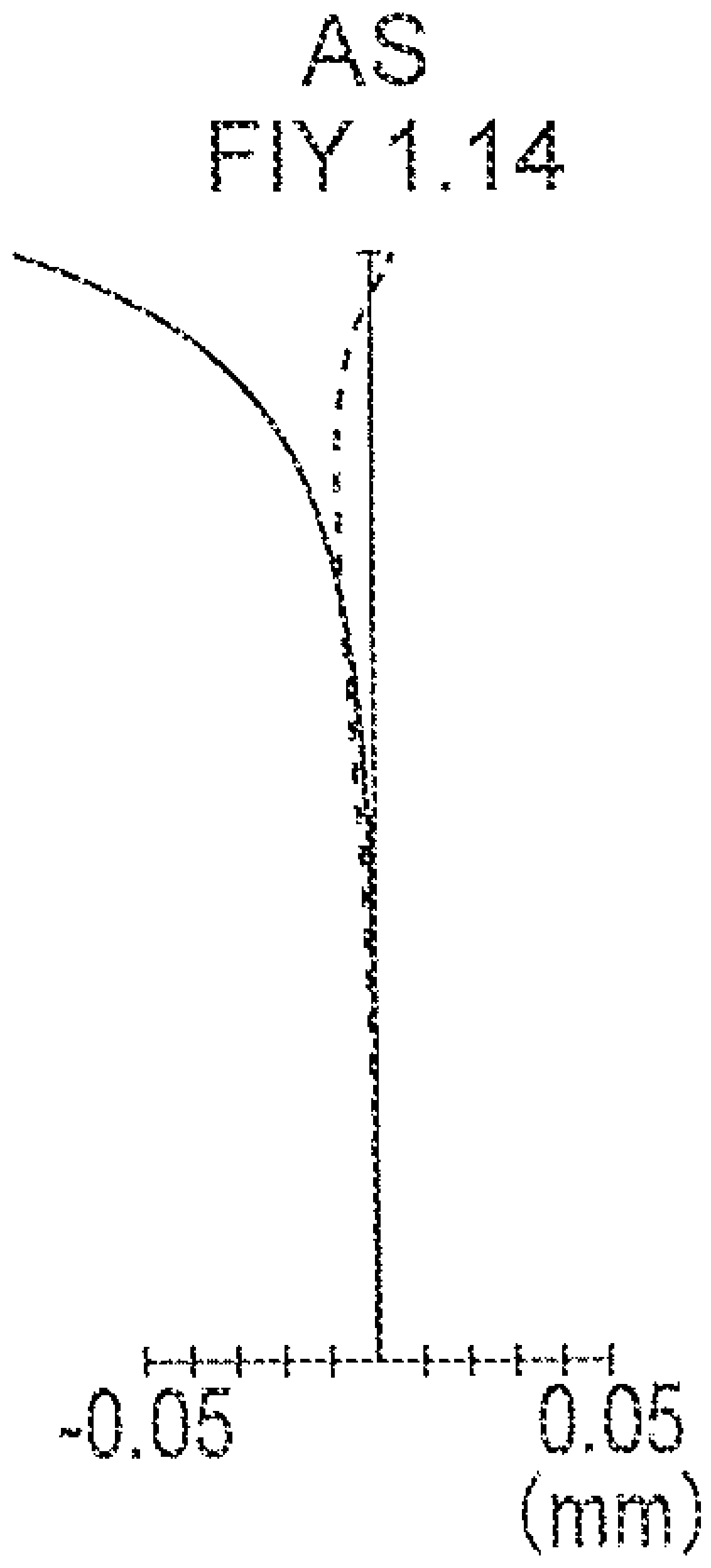


FIG. 17G

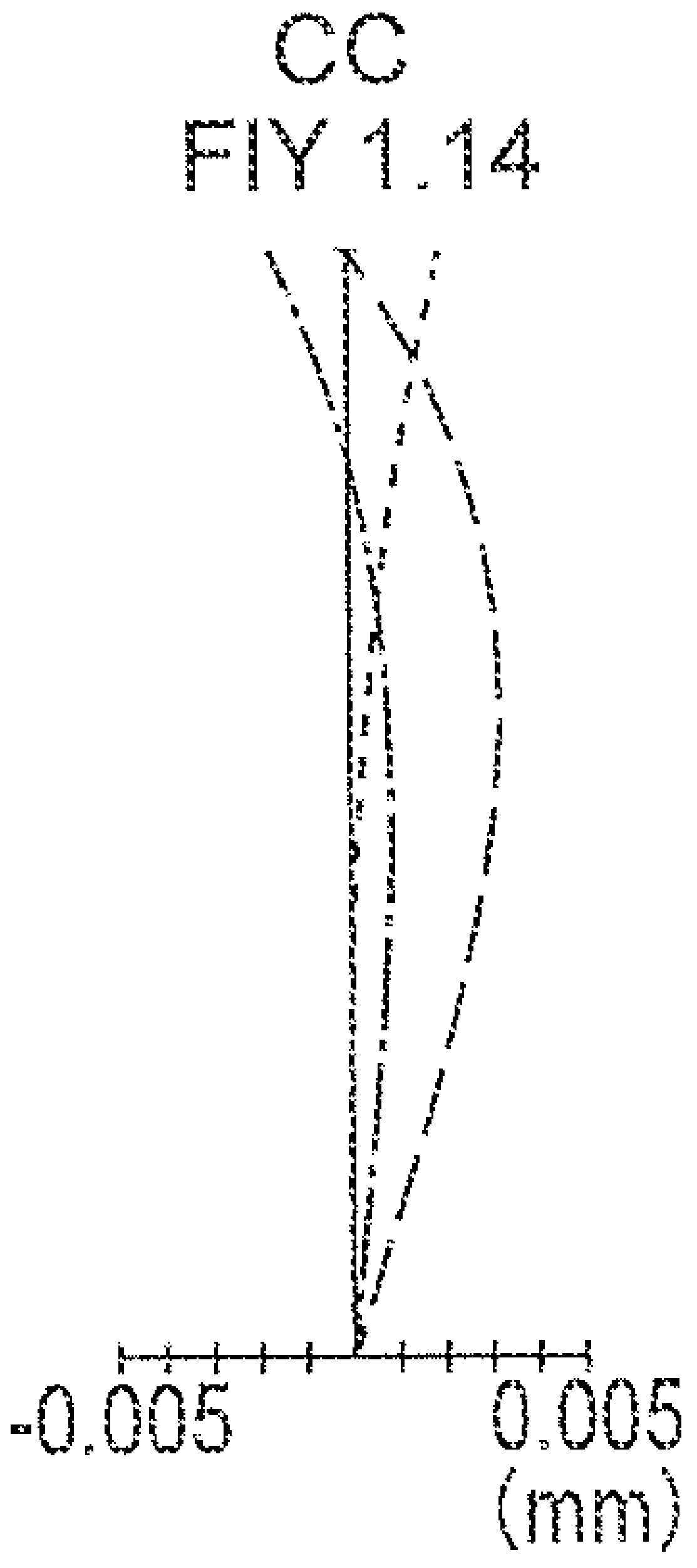


FIG. 17H

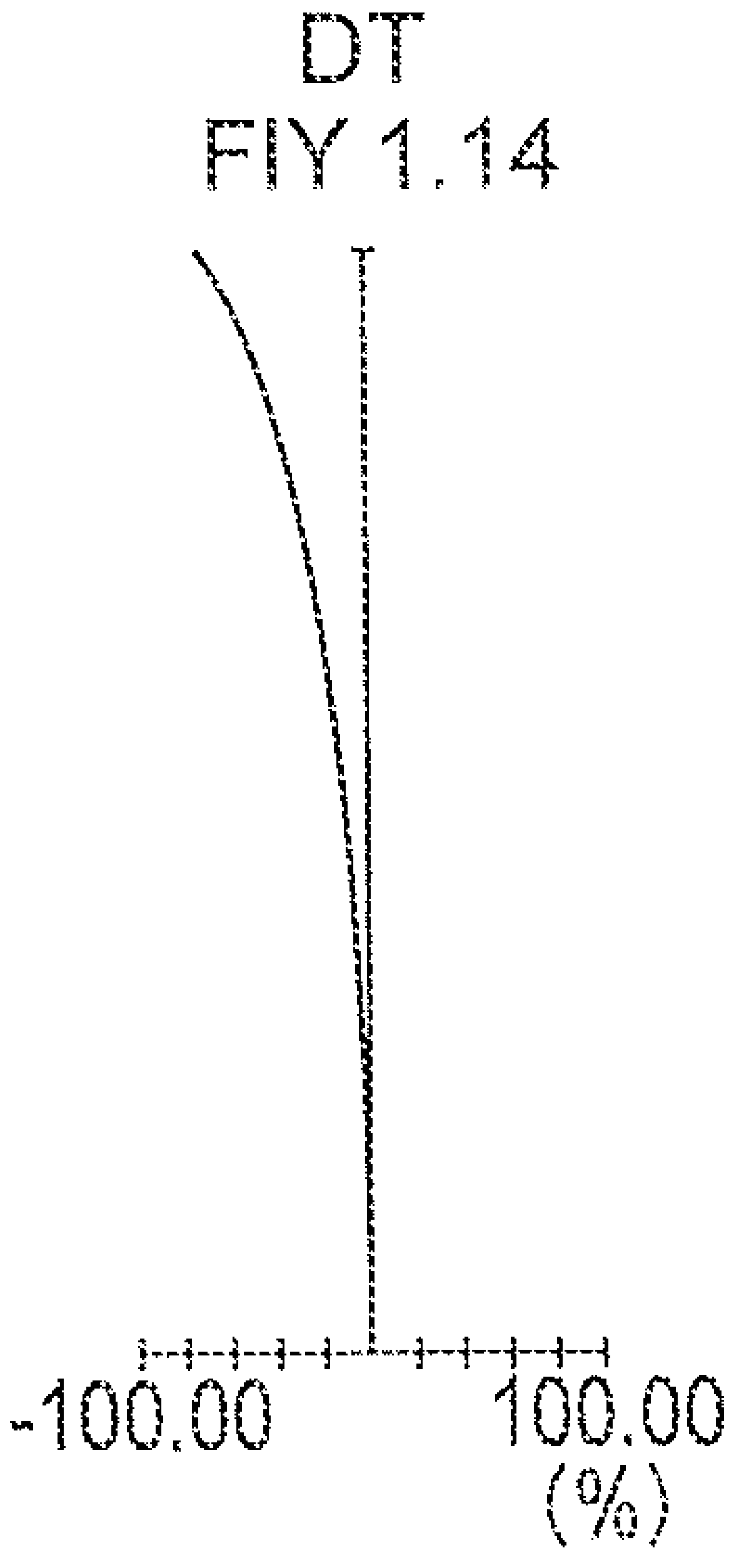


FIG. 18A

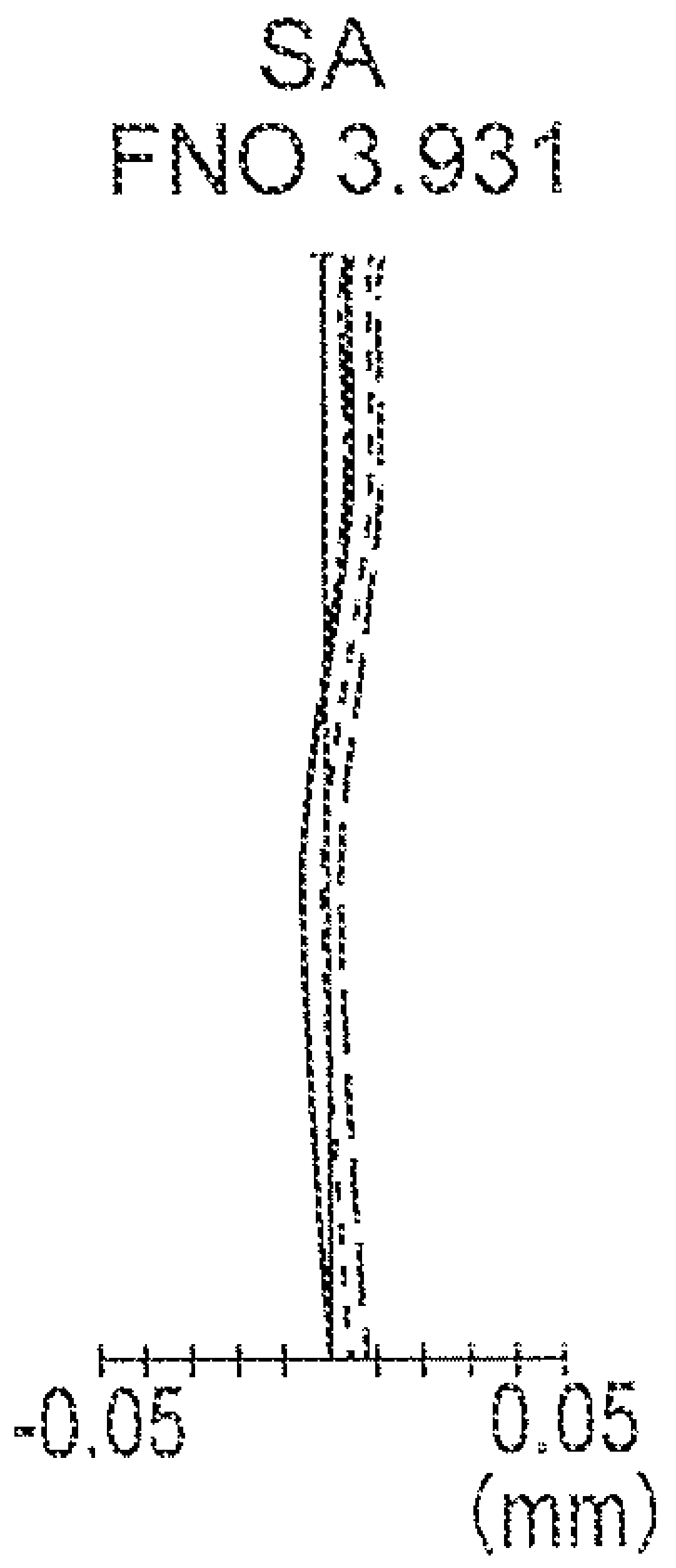


FIG. 18B

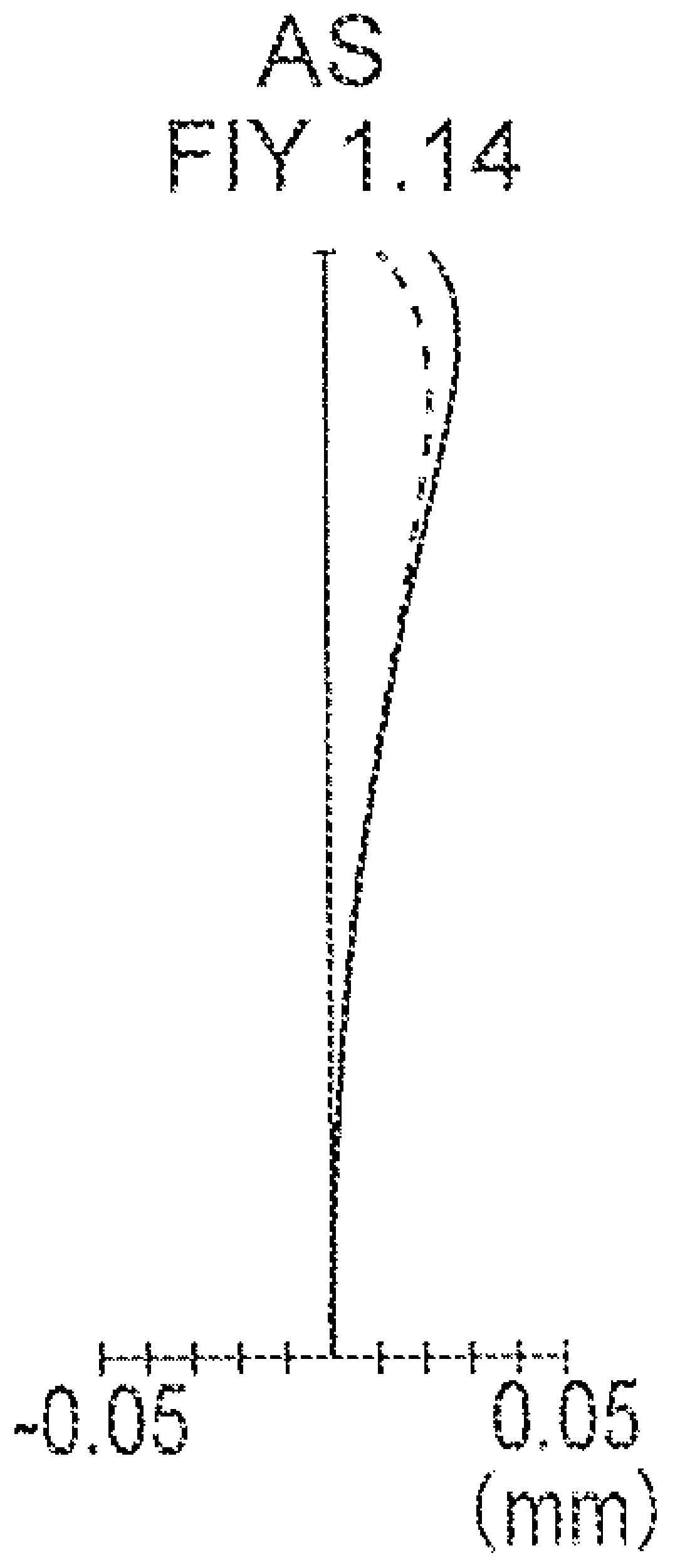


FIG. 18C

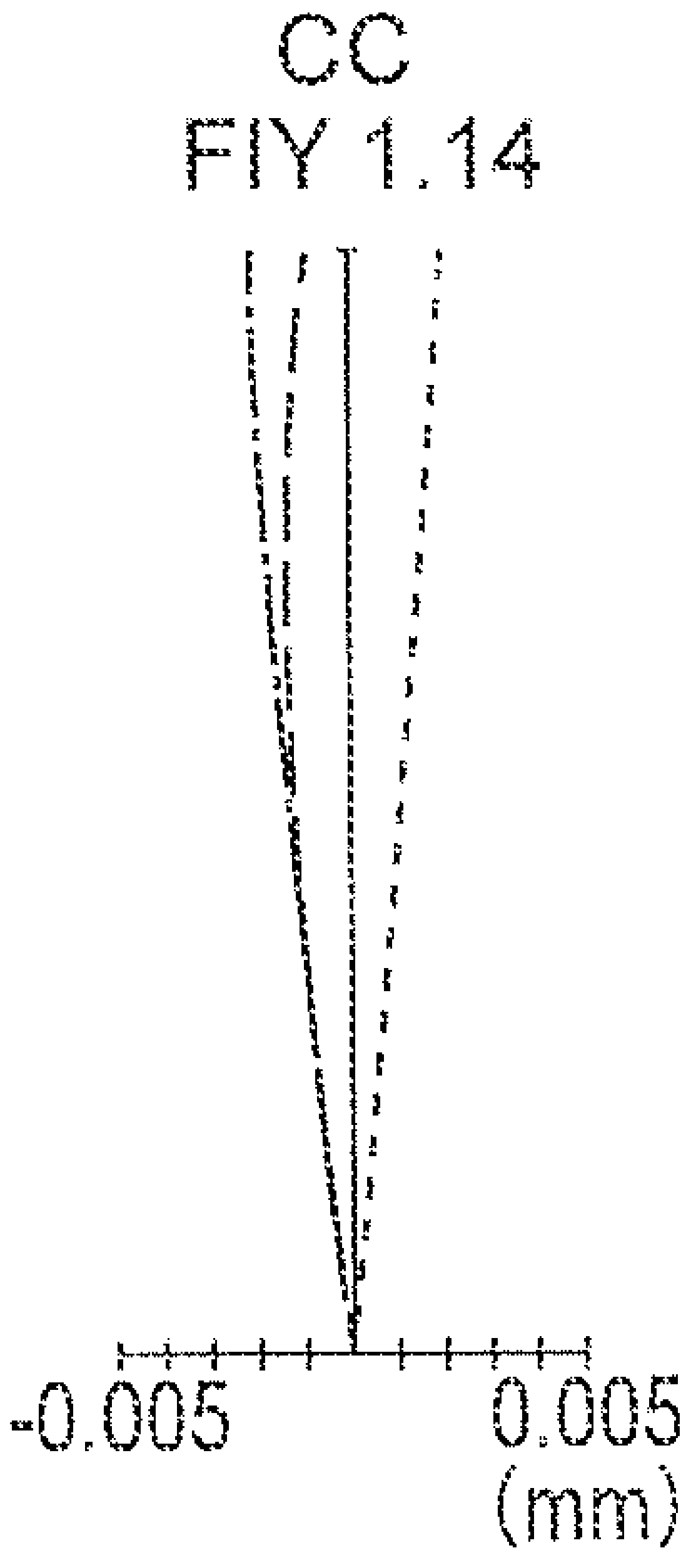


FIG. 18D

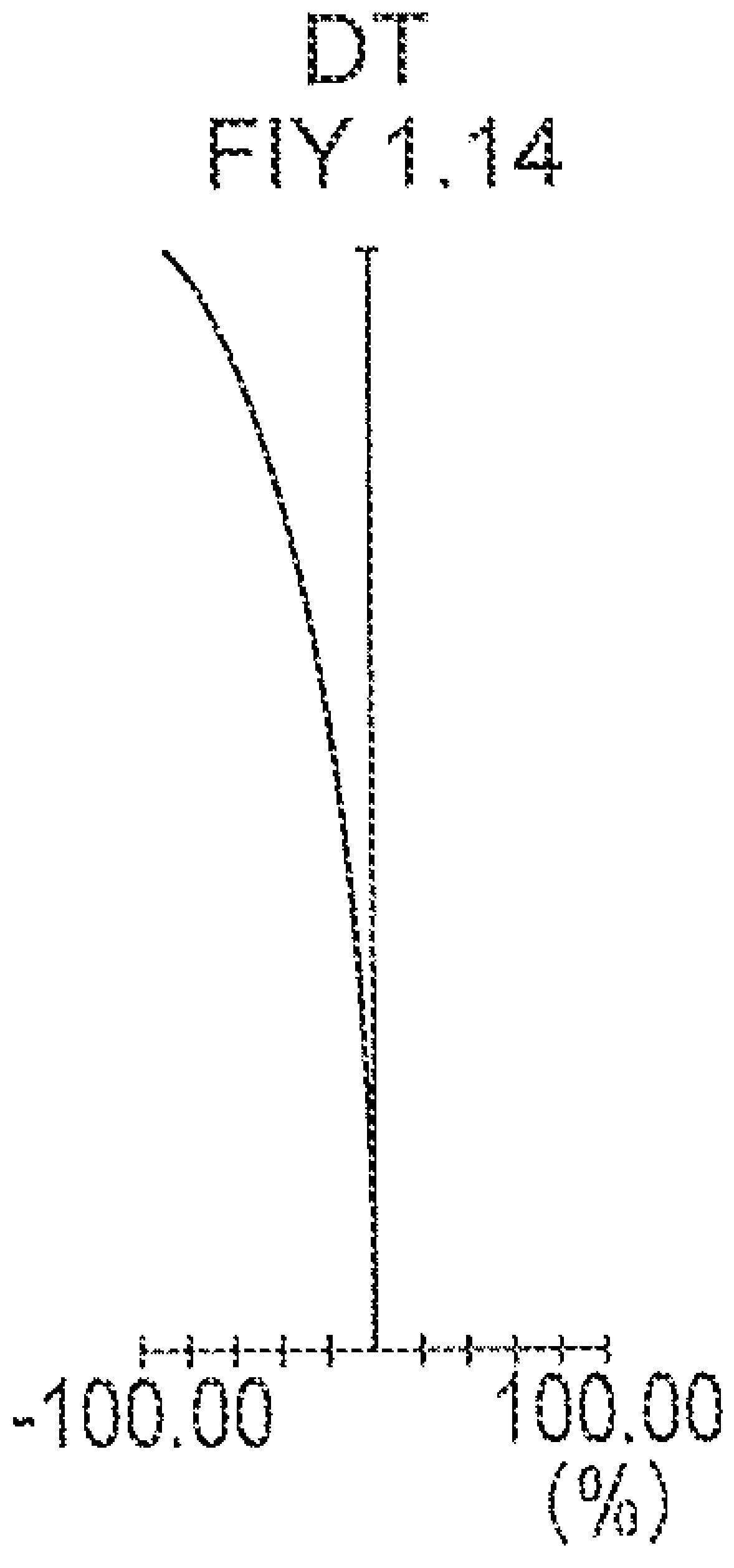


FIG. 18E

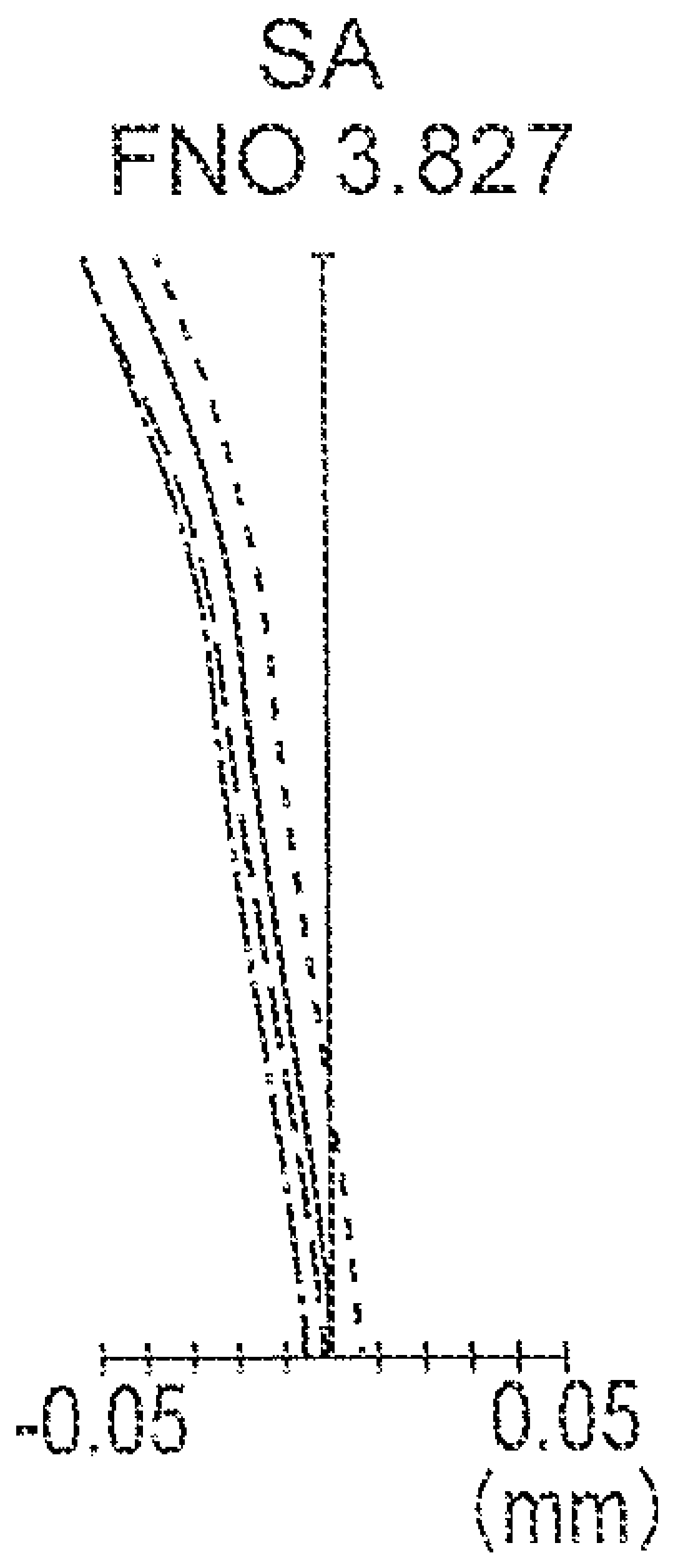


FIG. 18F

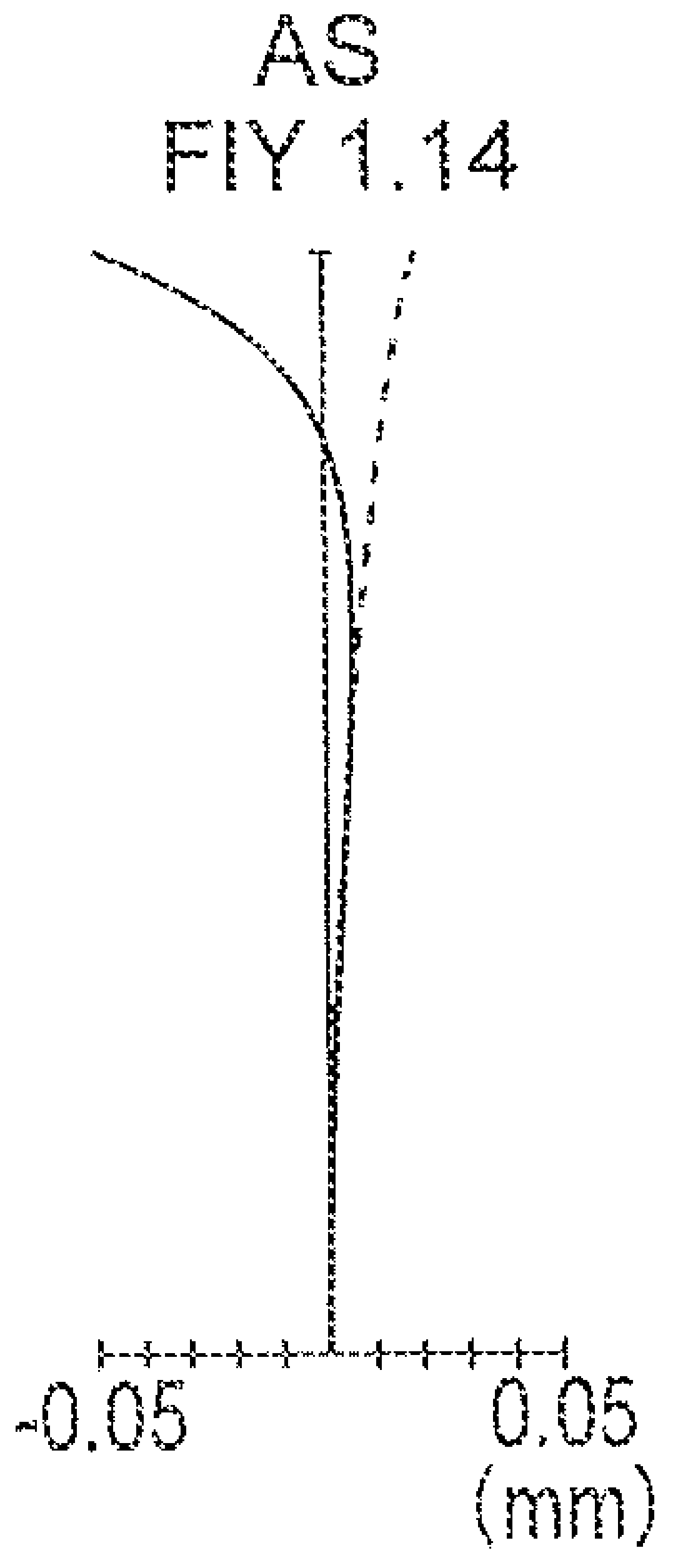


FIG. 18G

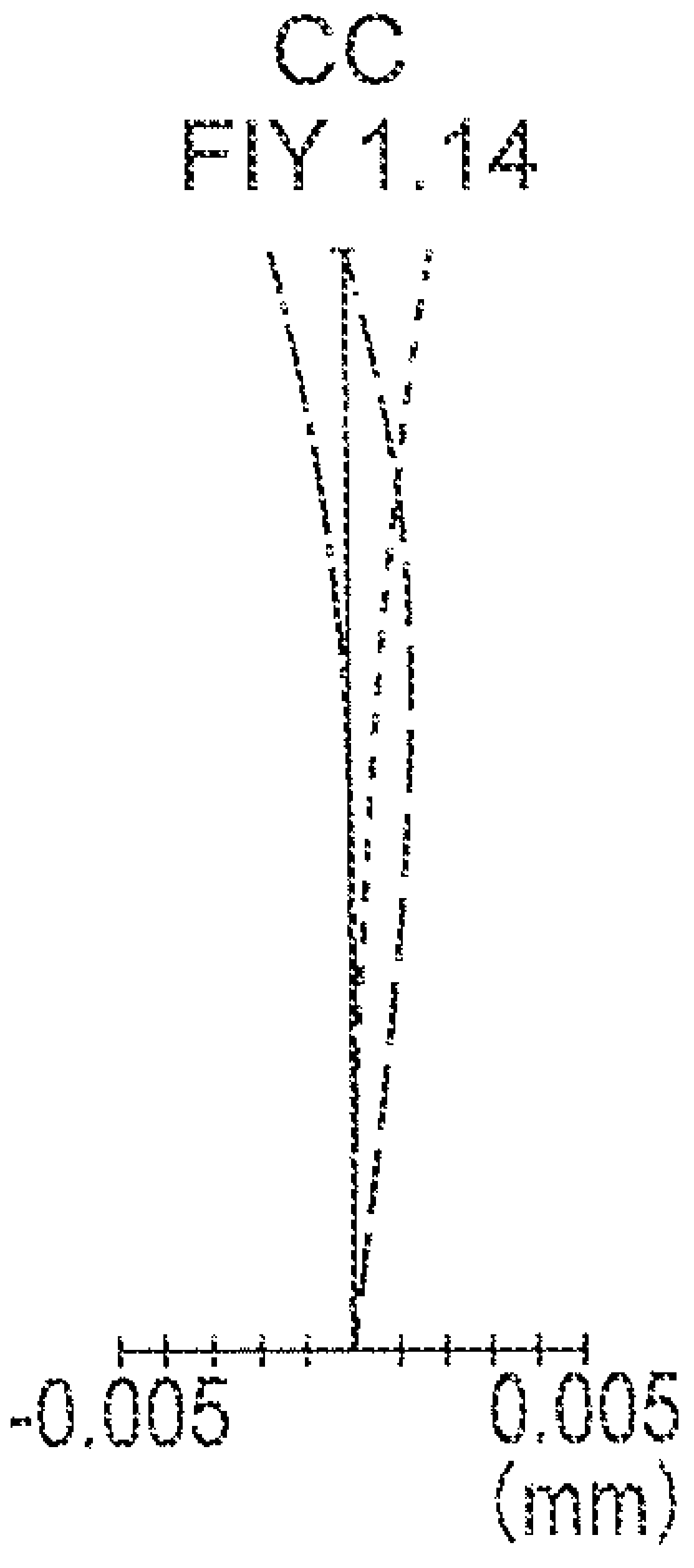


FIG. 18H

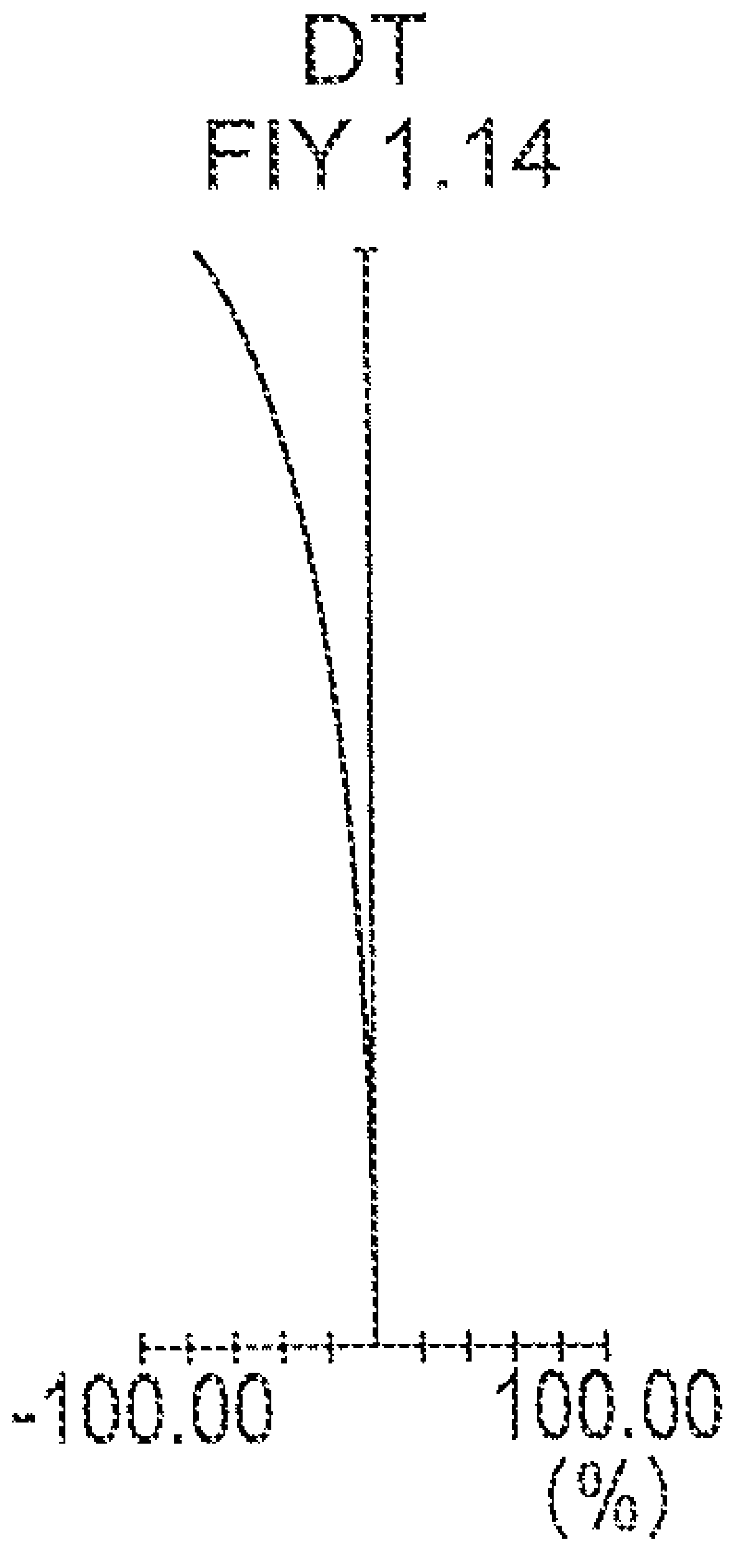


FIG. 19A

SA
FNO 3.940

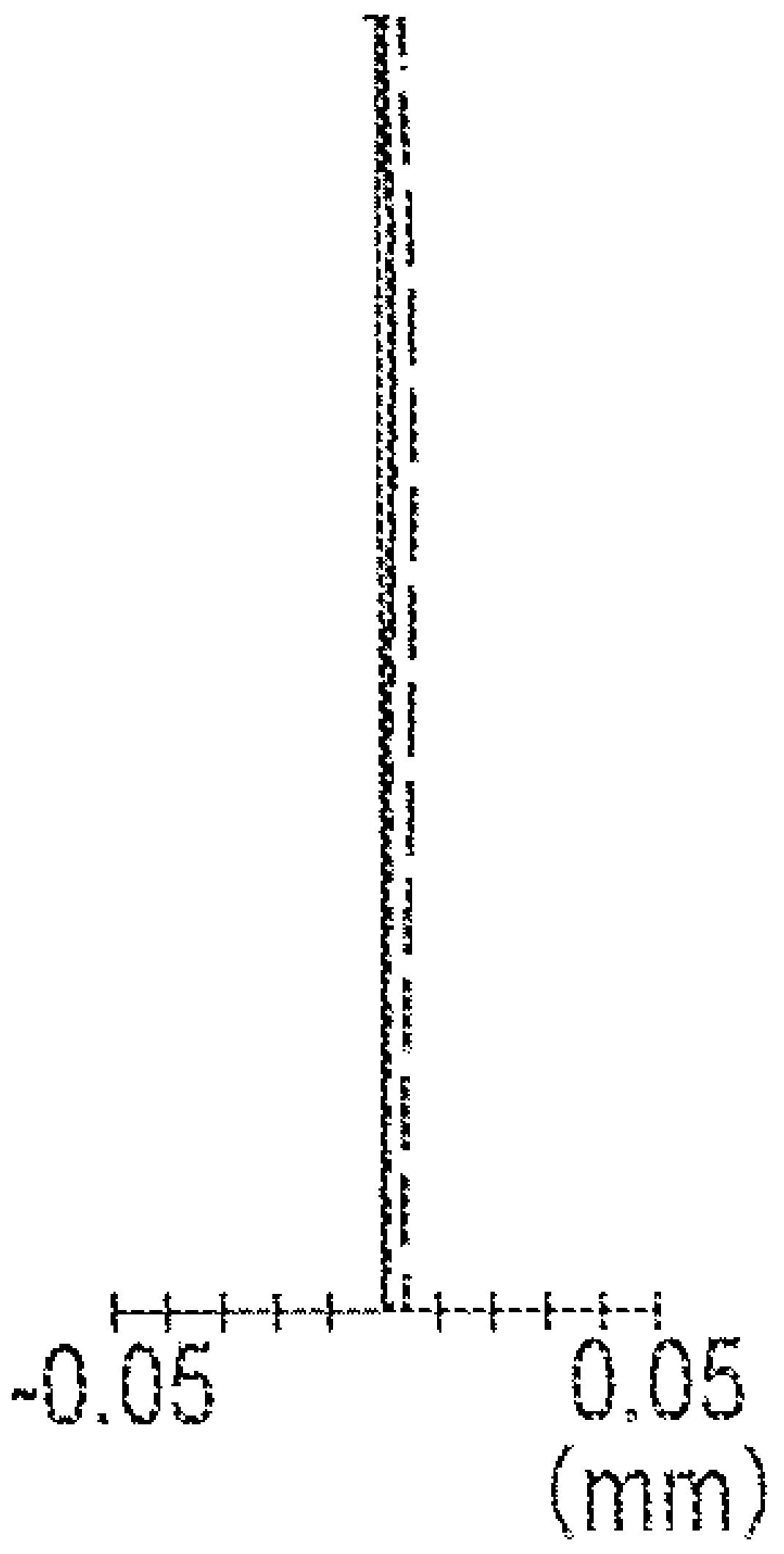


FIG. 19B

AS
FIY 1.14

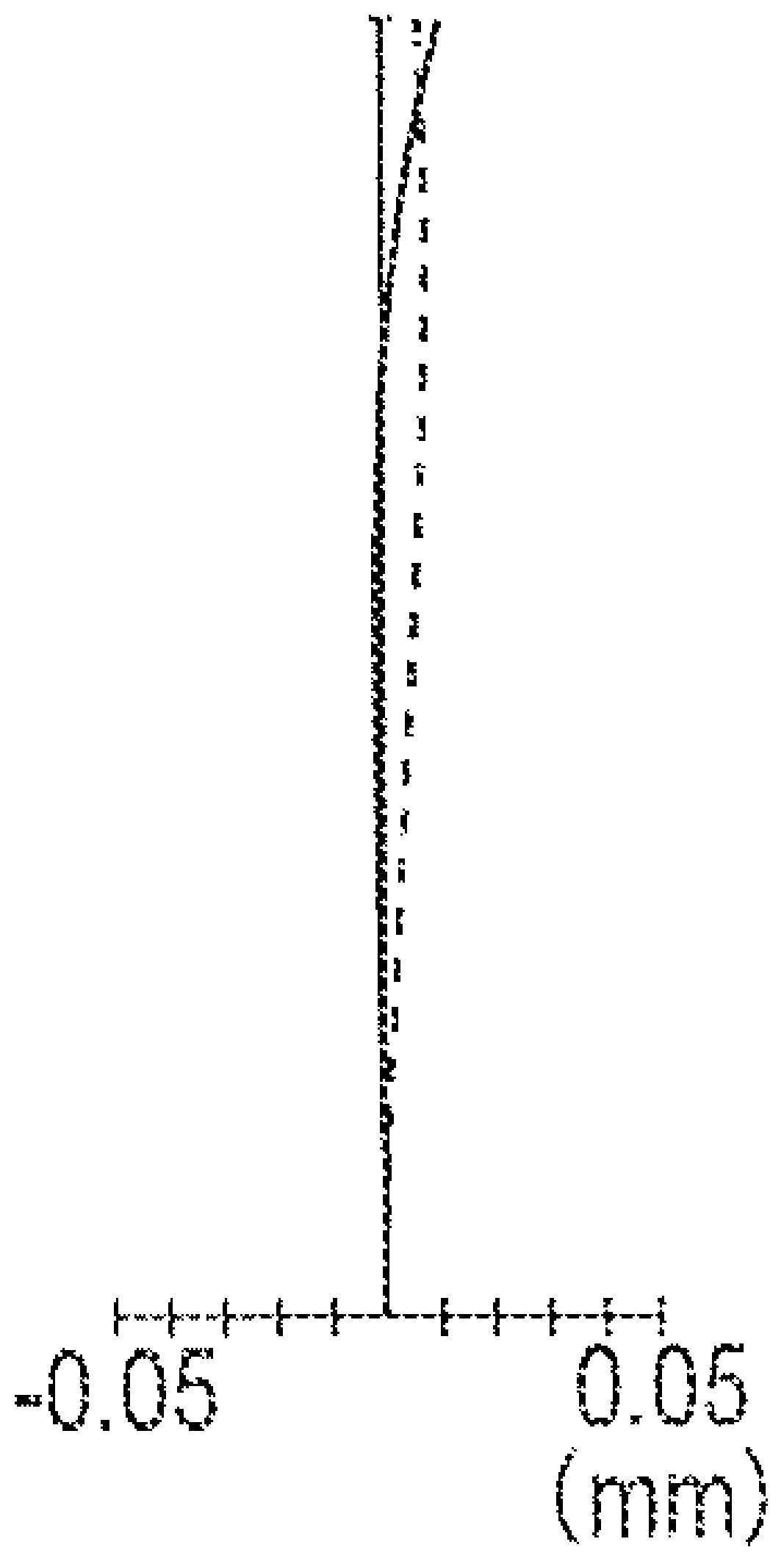


FIG. 19C

CC
FIY 1.14

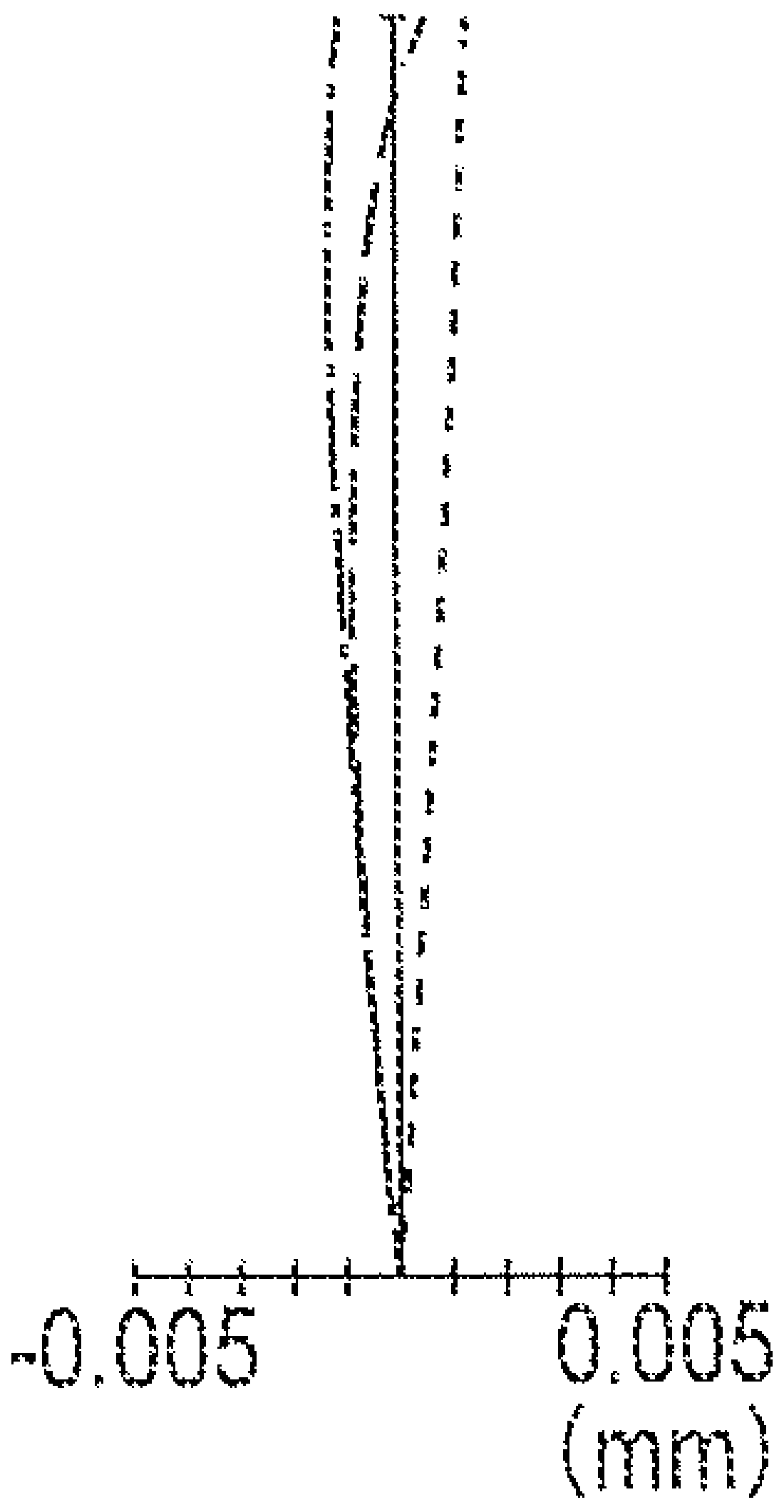


FIG. 19D

DT
FIY 1.14

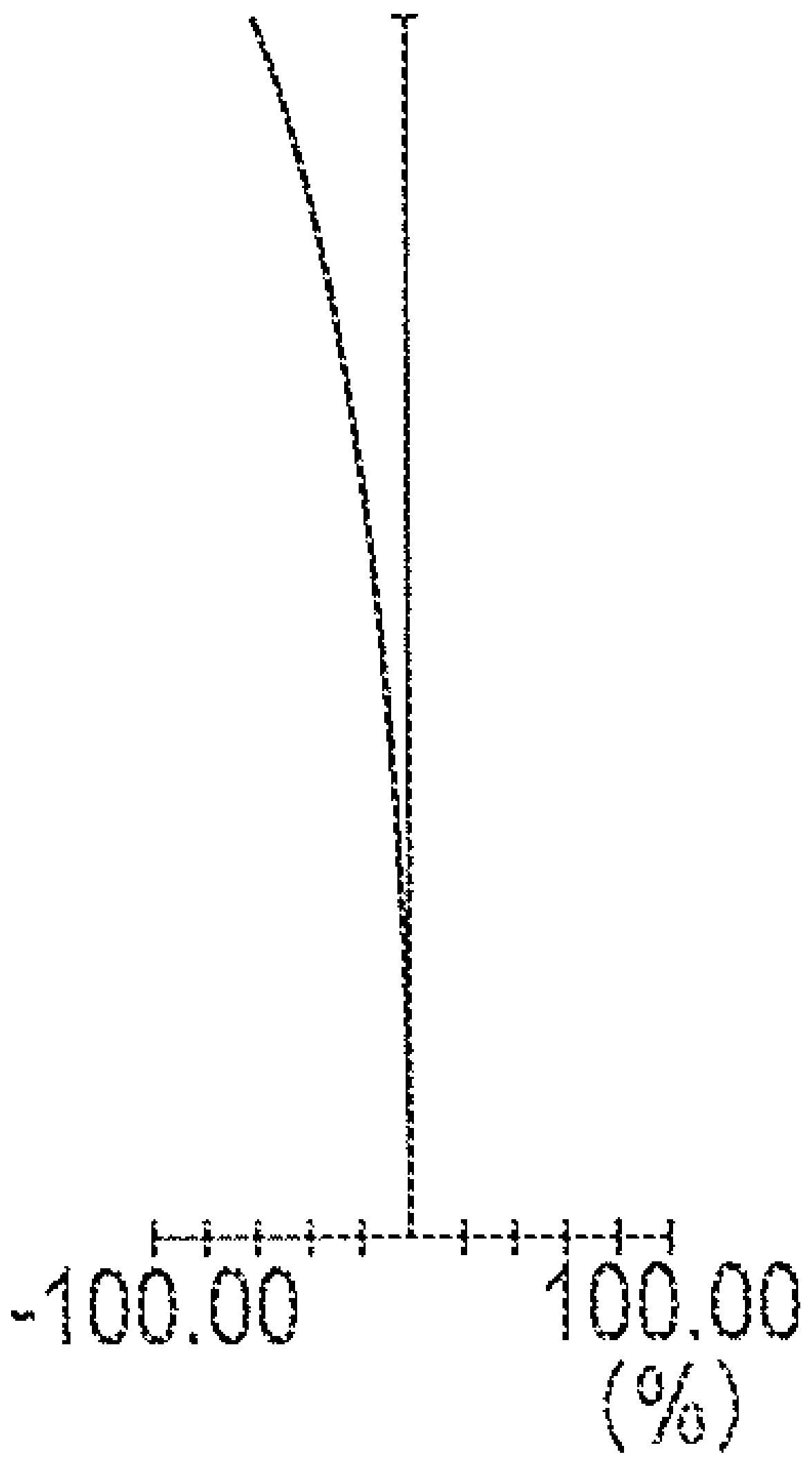


FIG. 19E

SA
FNO 3.905

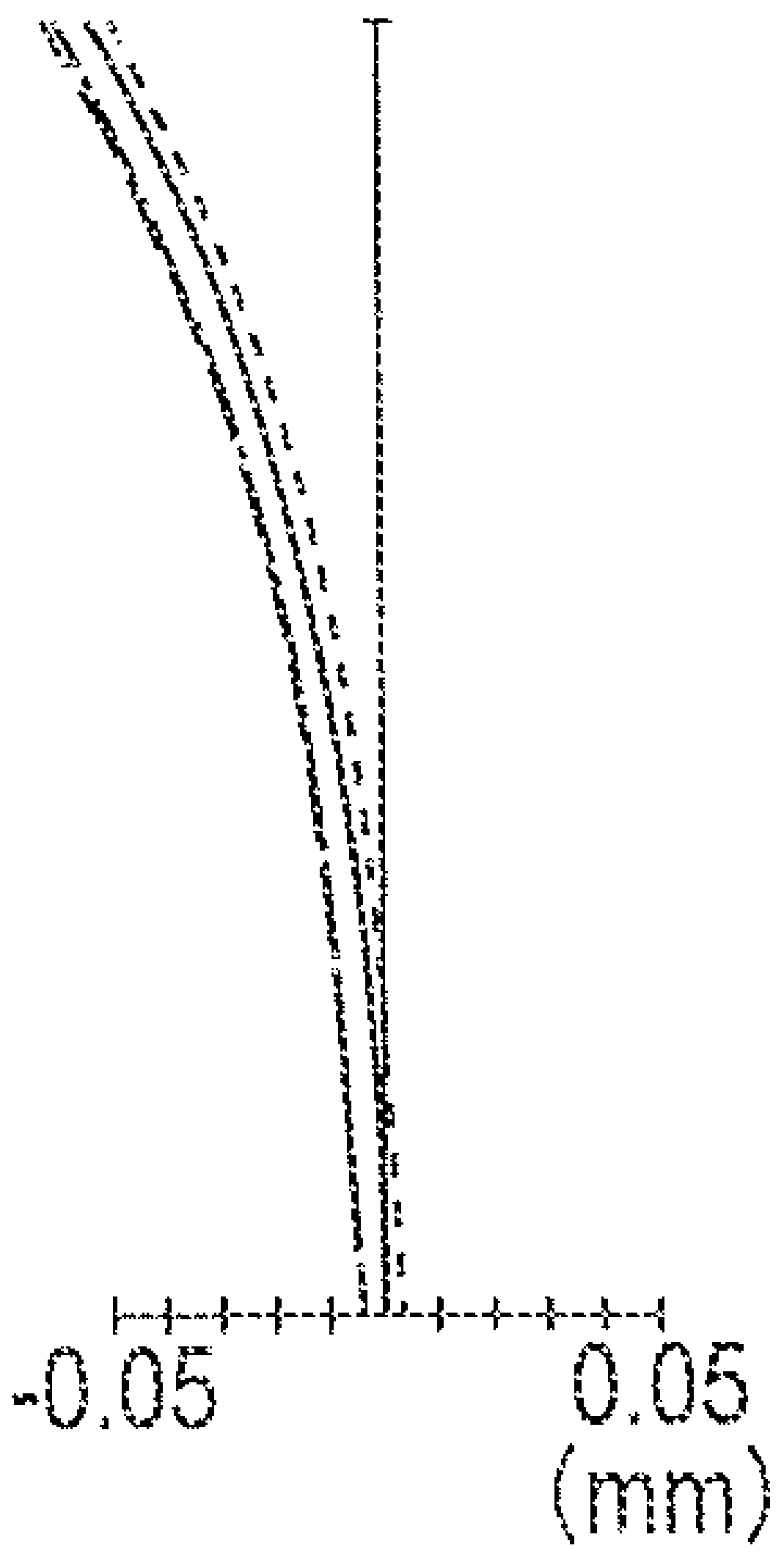


FIG. 19F

AS
FIY 1.14

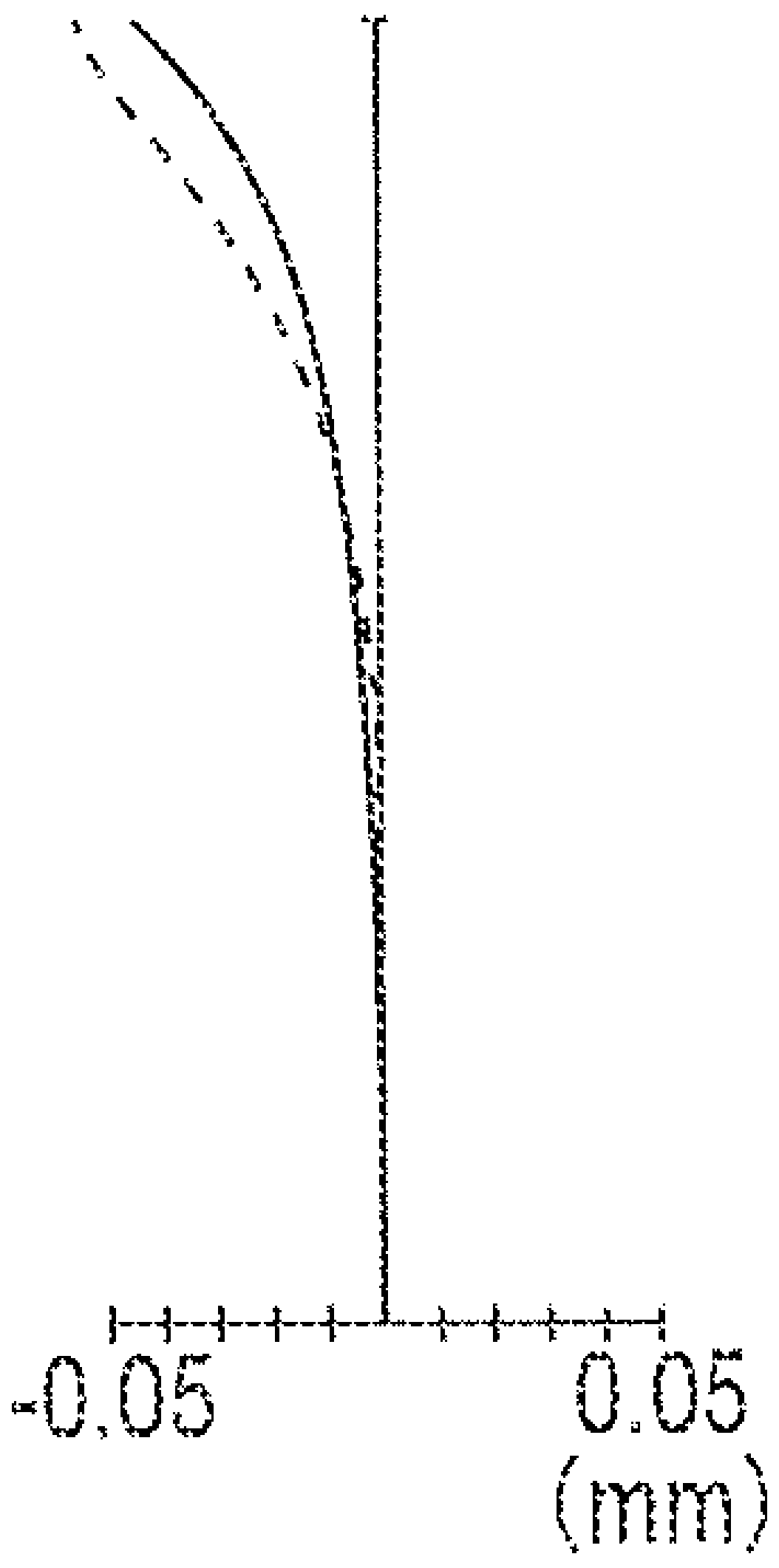


FIG. 19G

CC
FIY 1.14

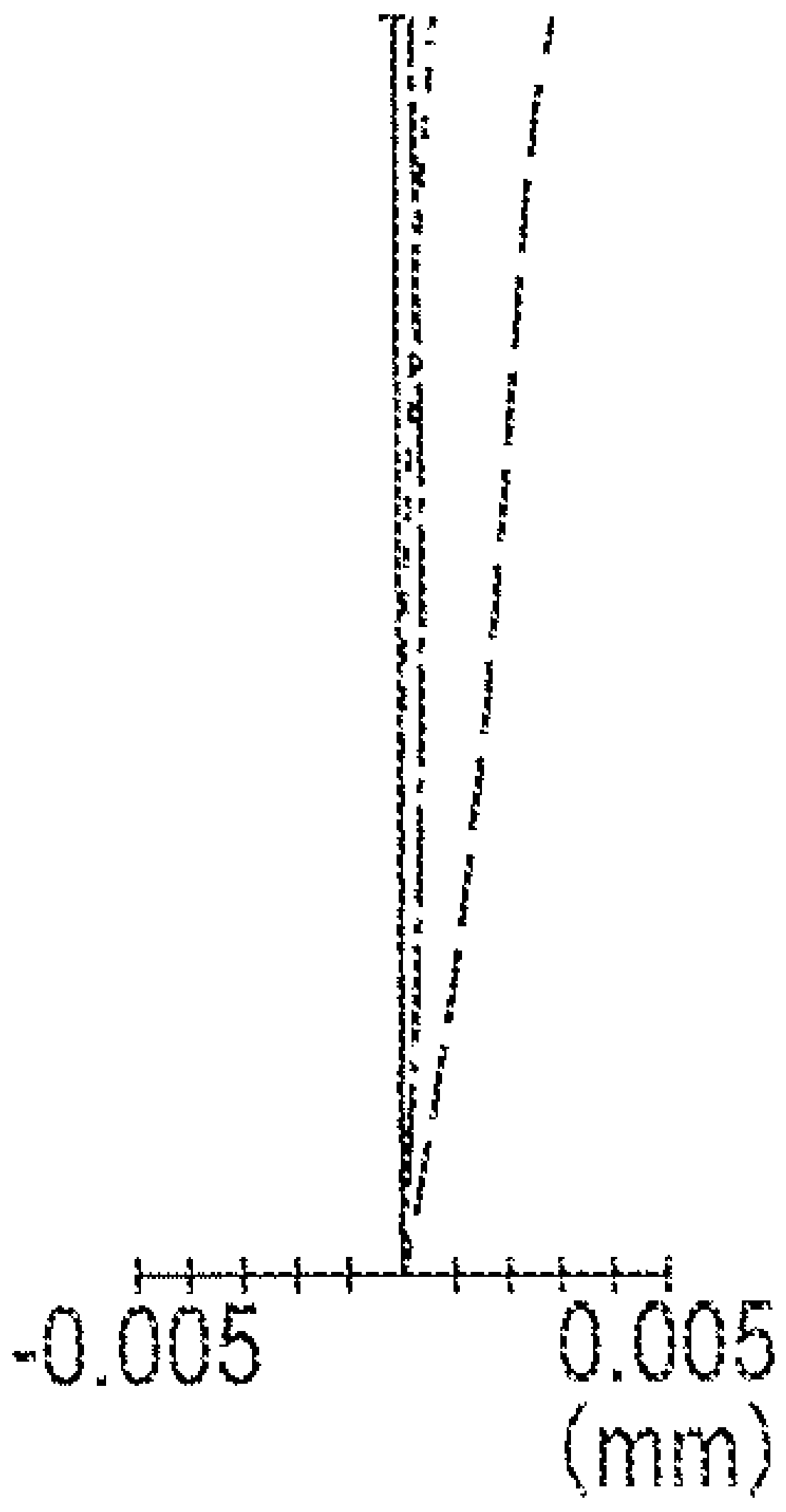


FIG. 19H

DT
FIY 1.14

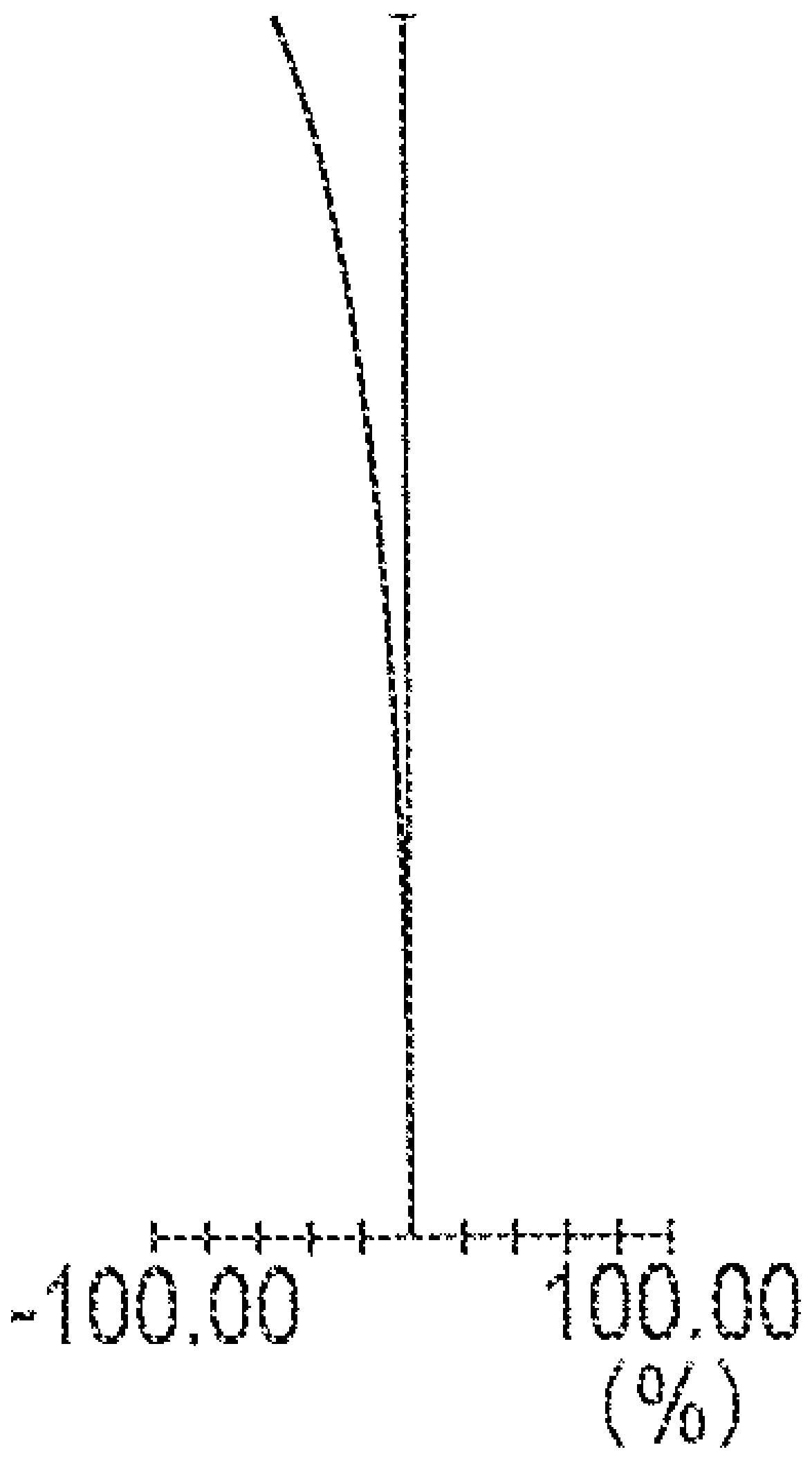


FIG. 20A

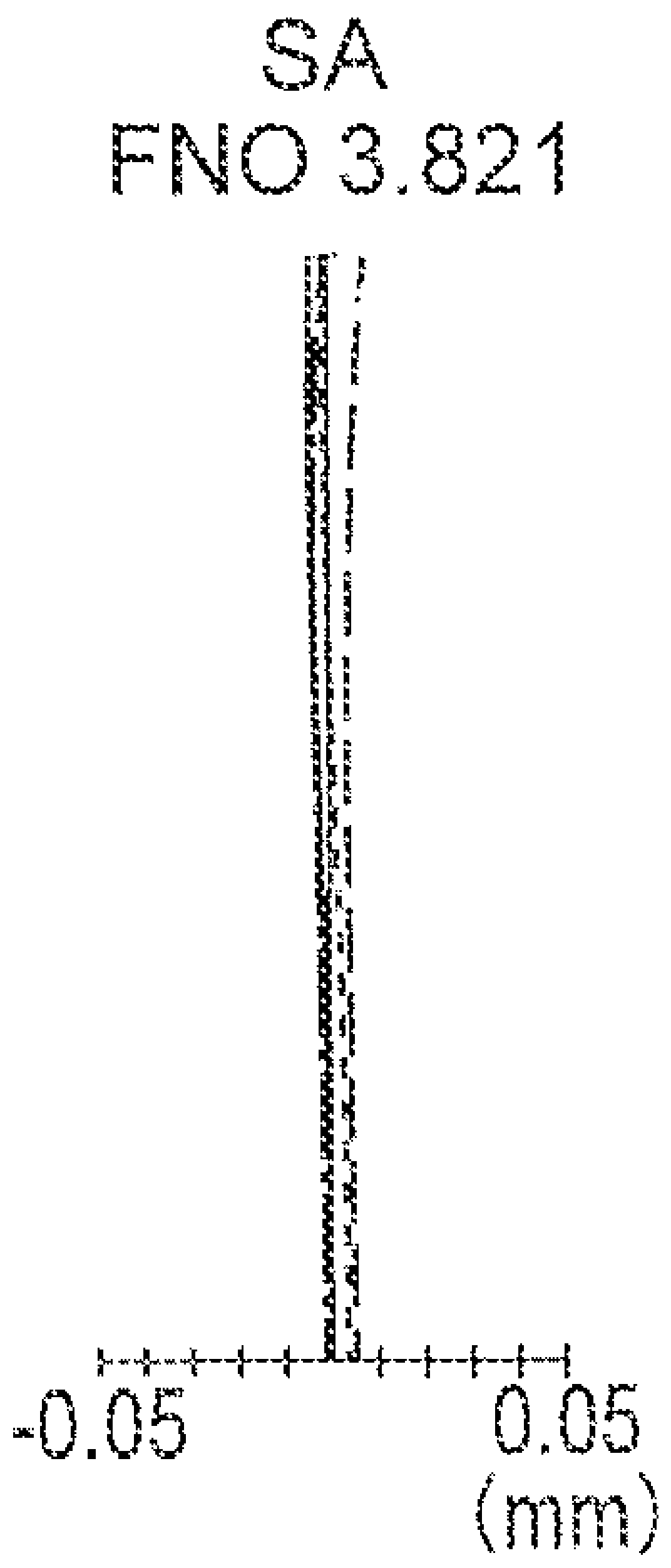


FIG. 20

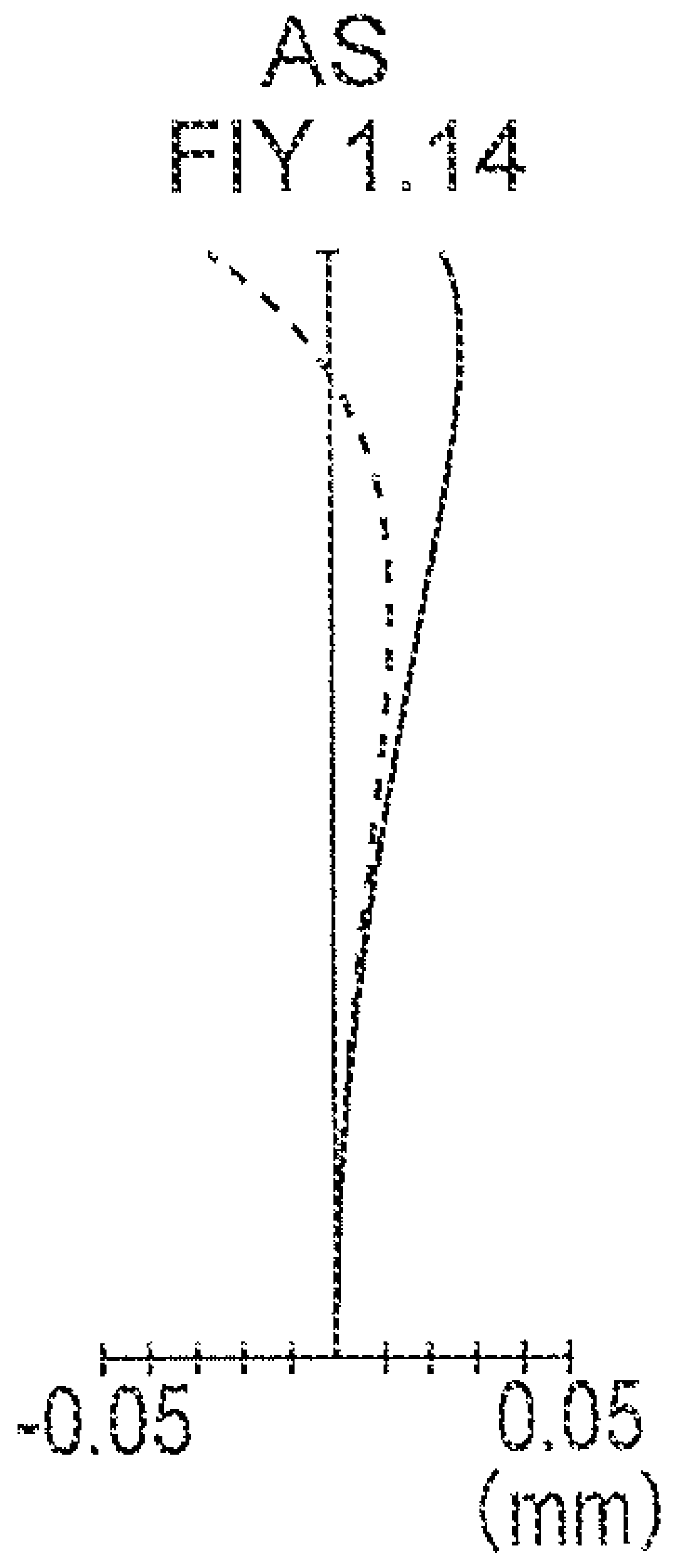


FIG. 20C

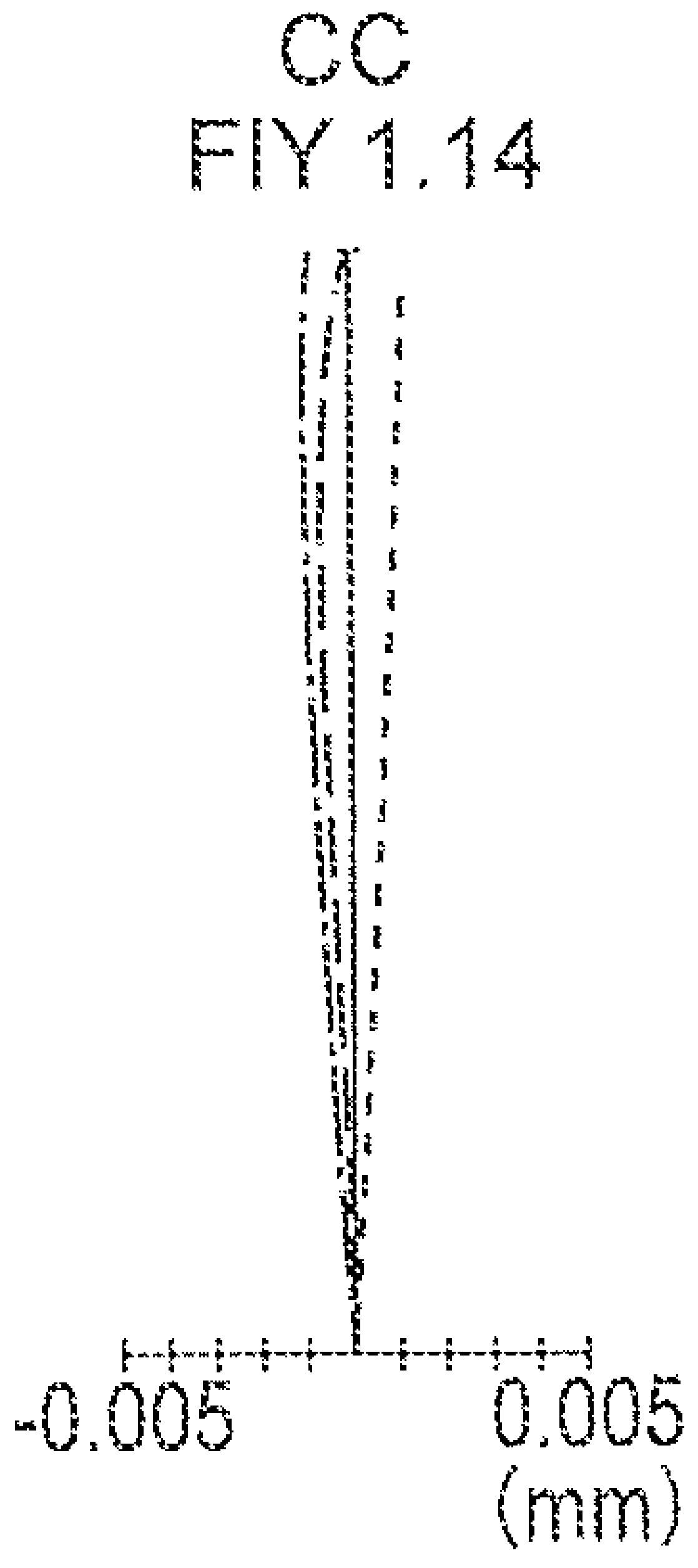


FIG. 20D

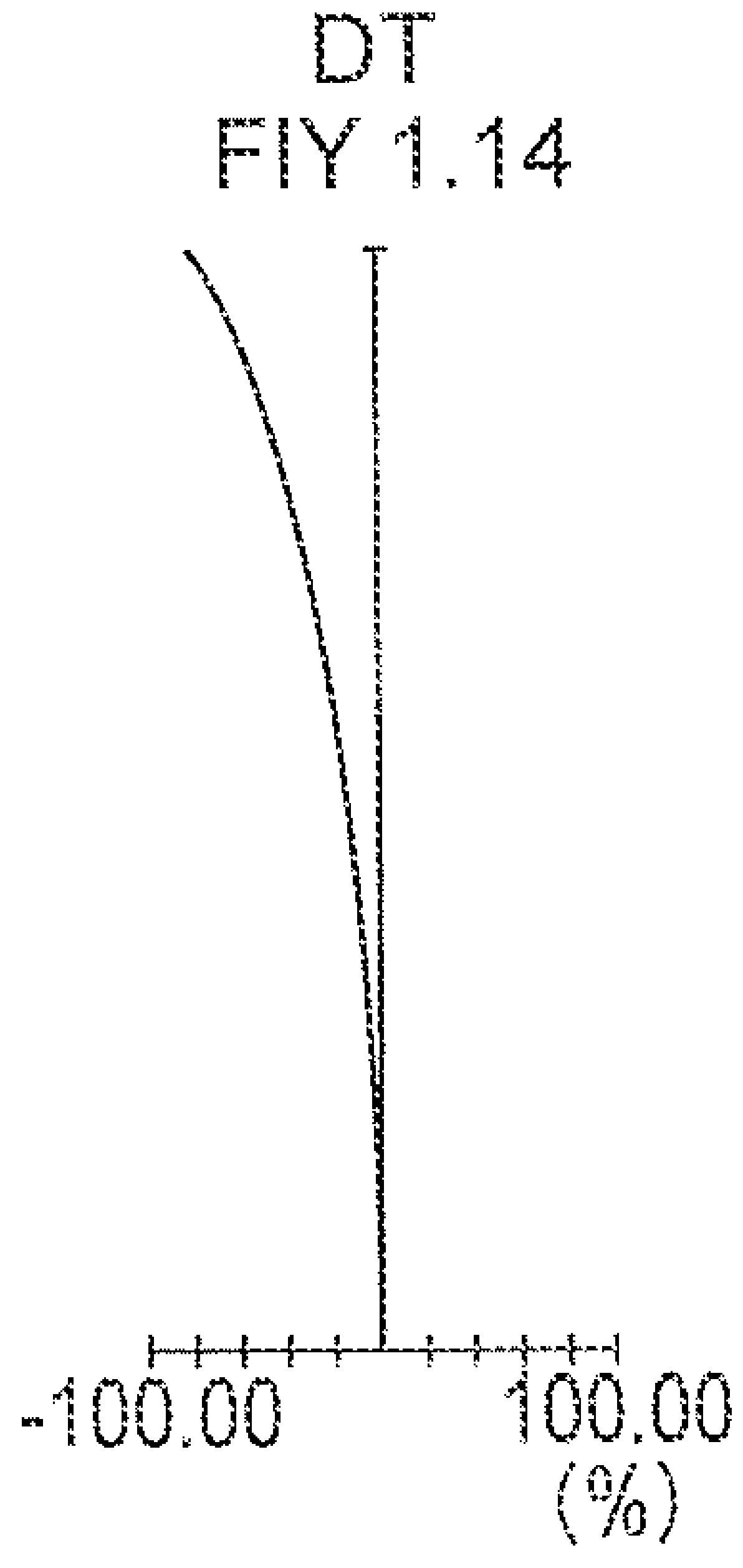


FIG. 20E

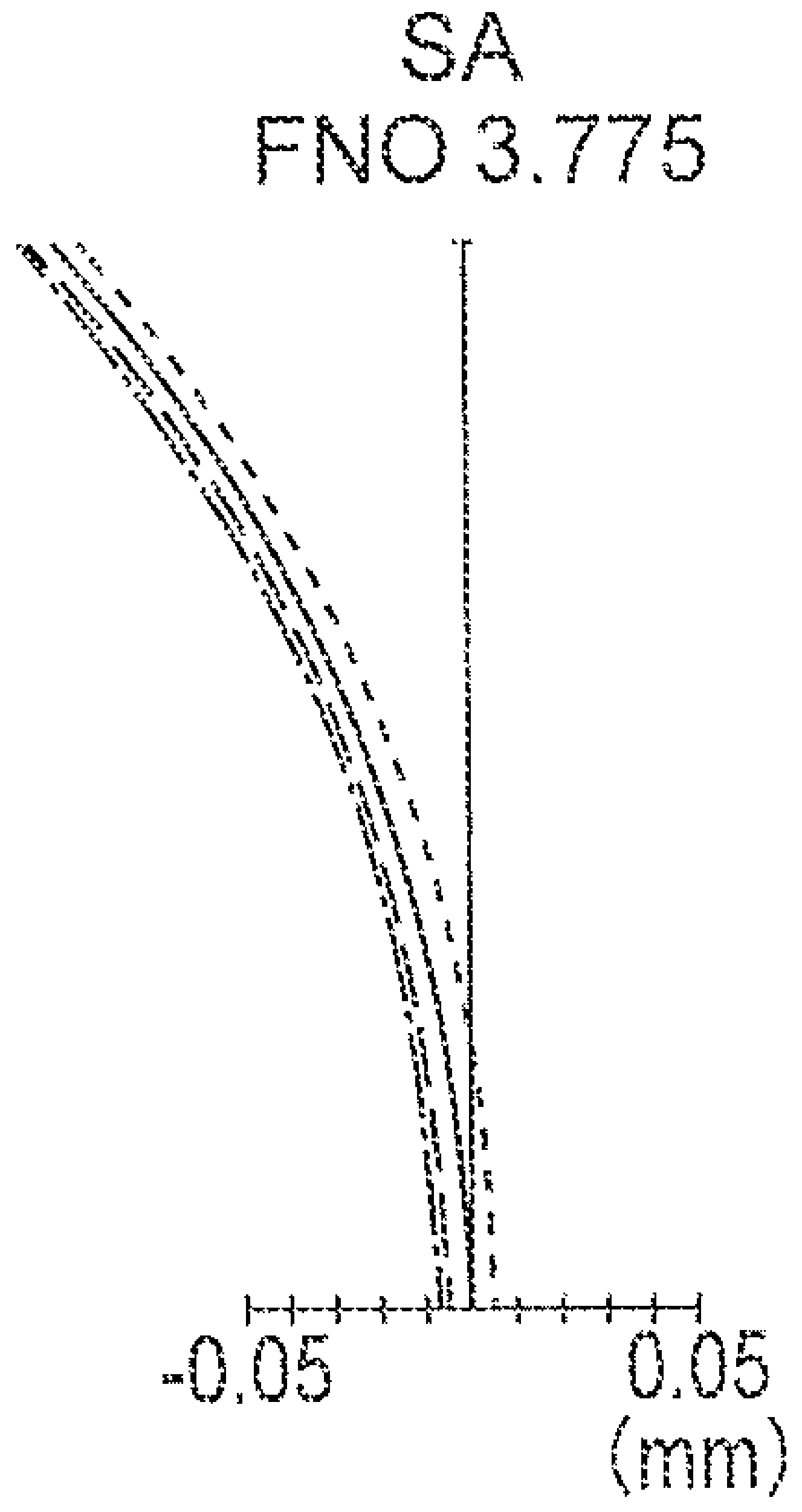


FIG. 20F

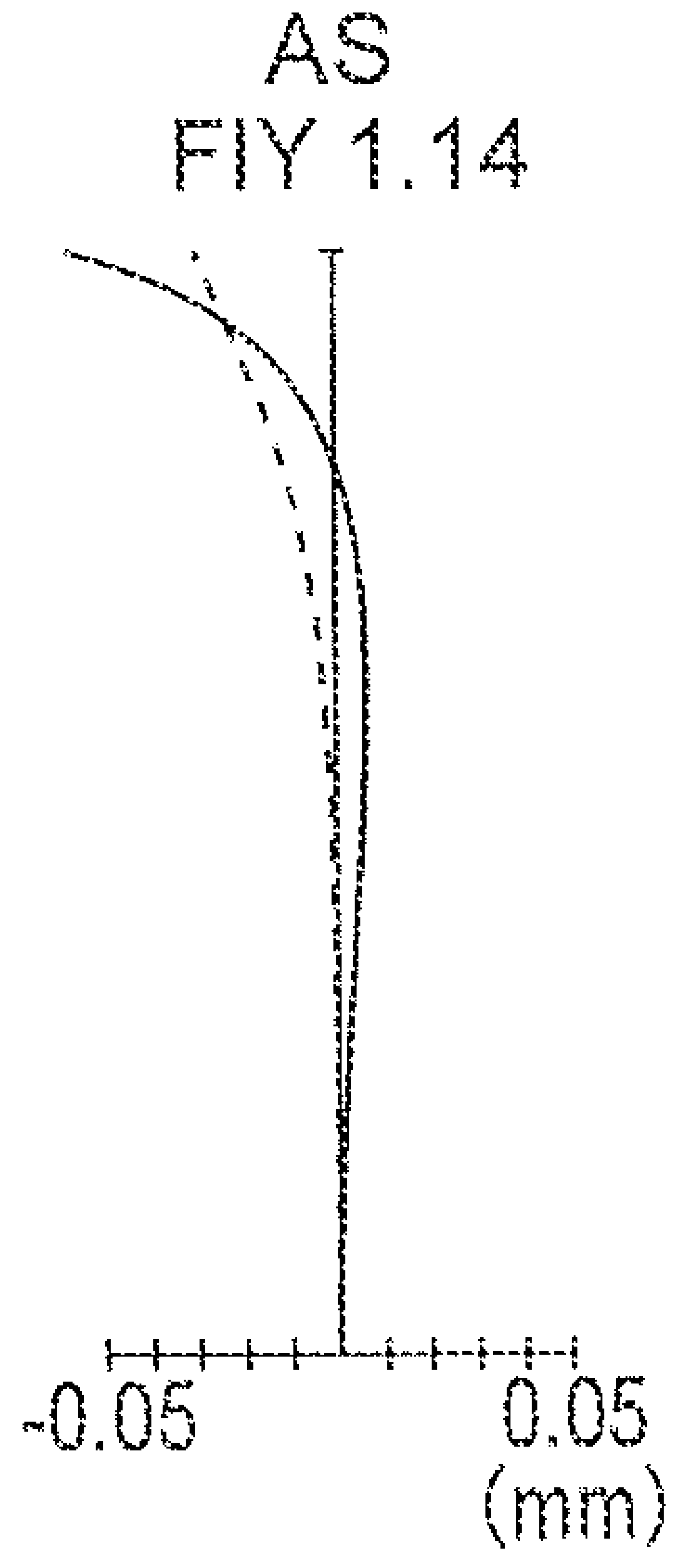


FIG. 20G

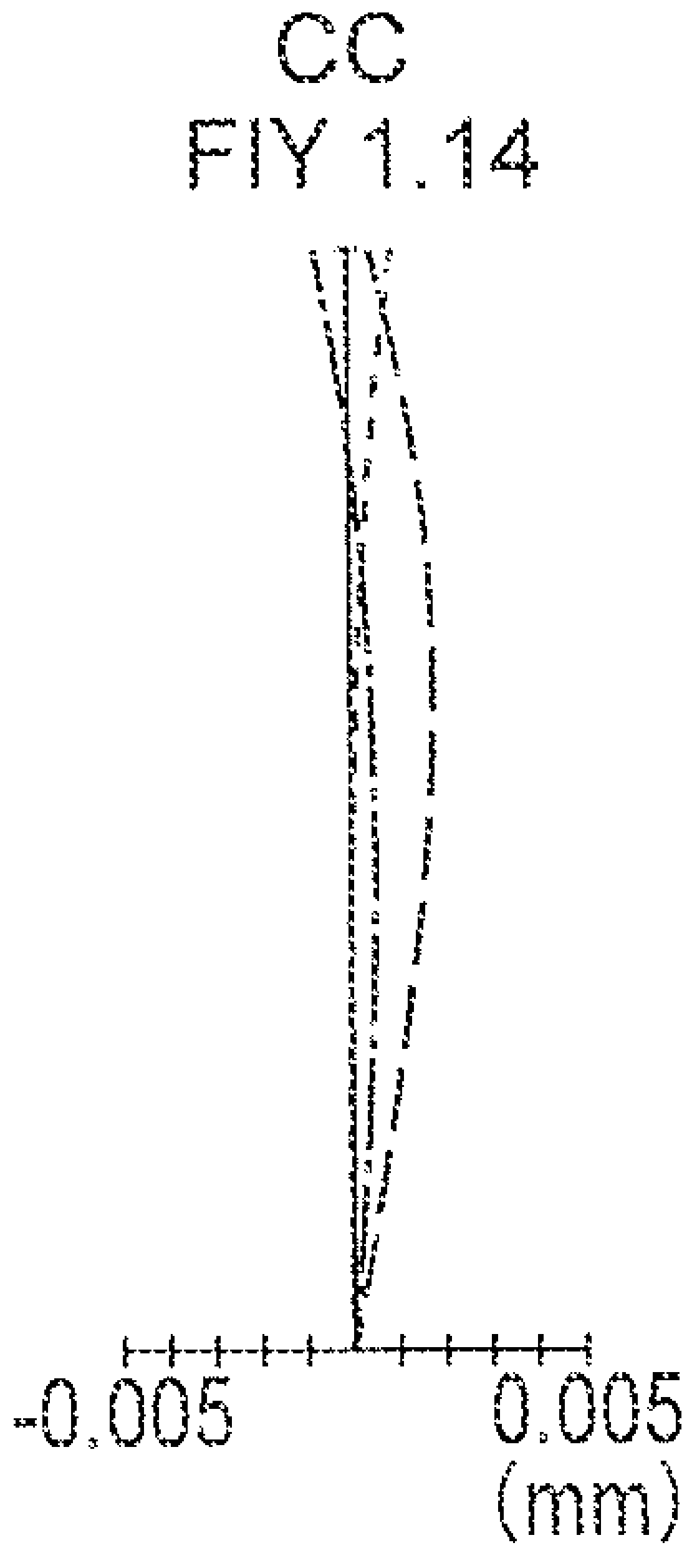


FIG. 20H

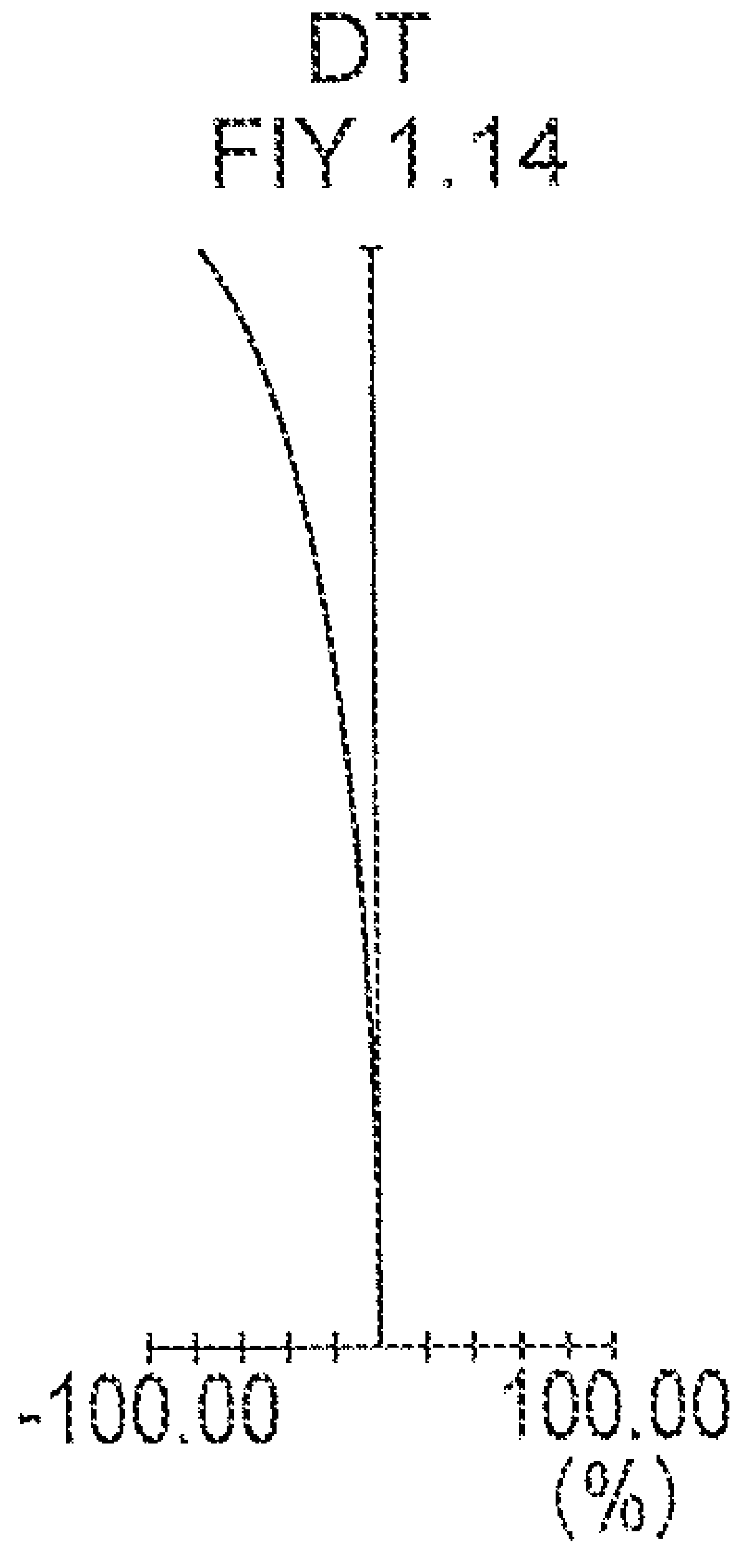


FIG. 21A

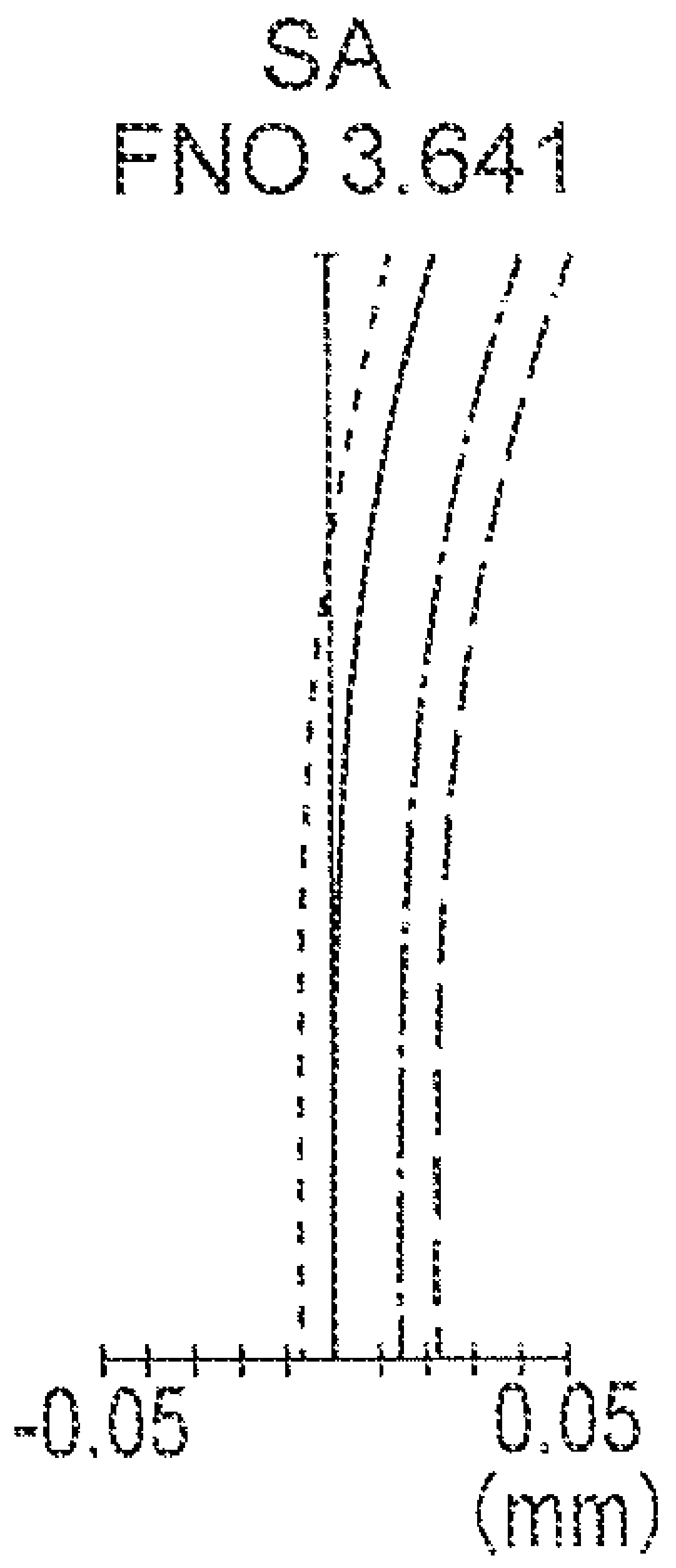


FIG. 21B

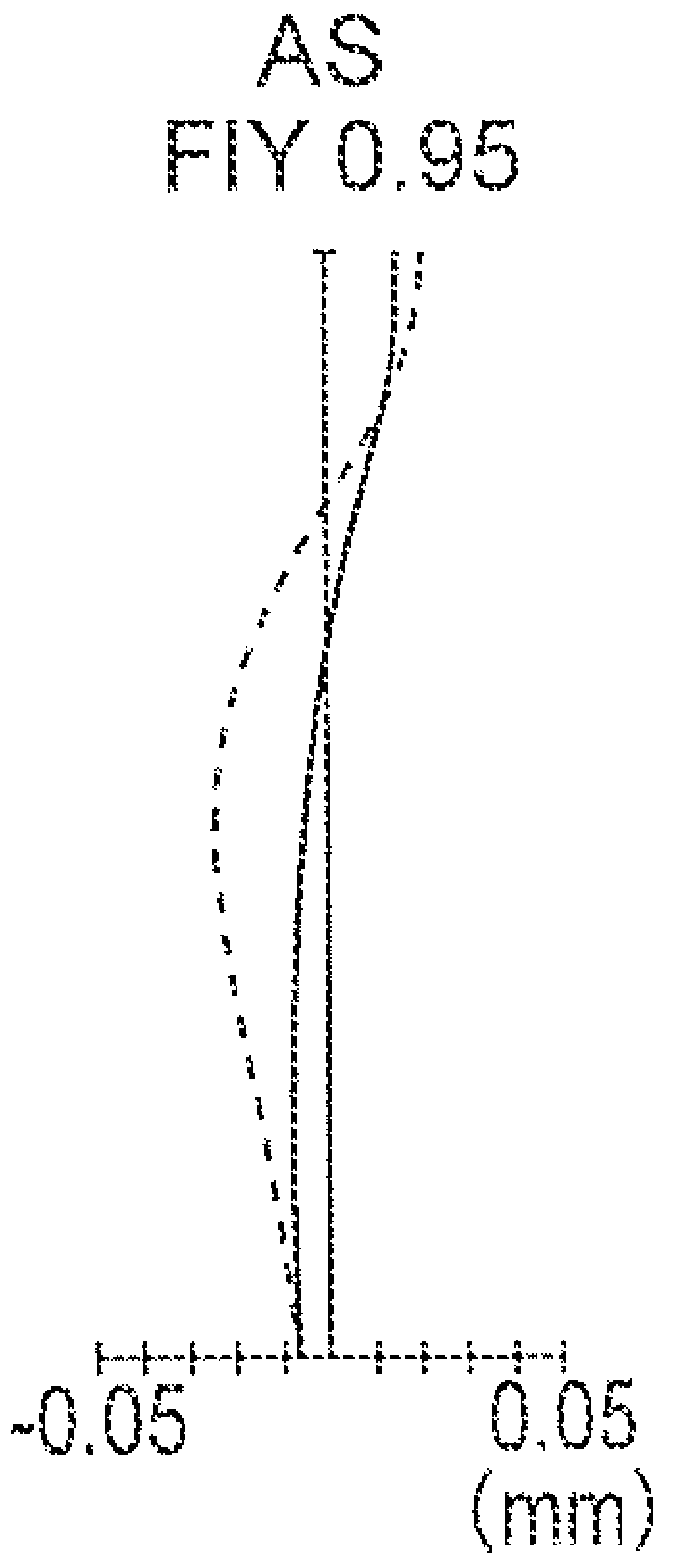


FIG. 21C

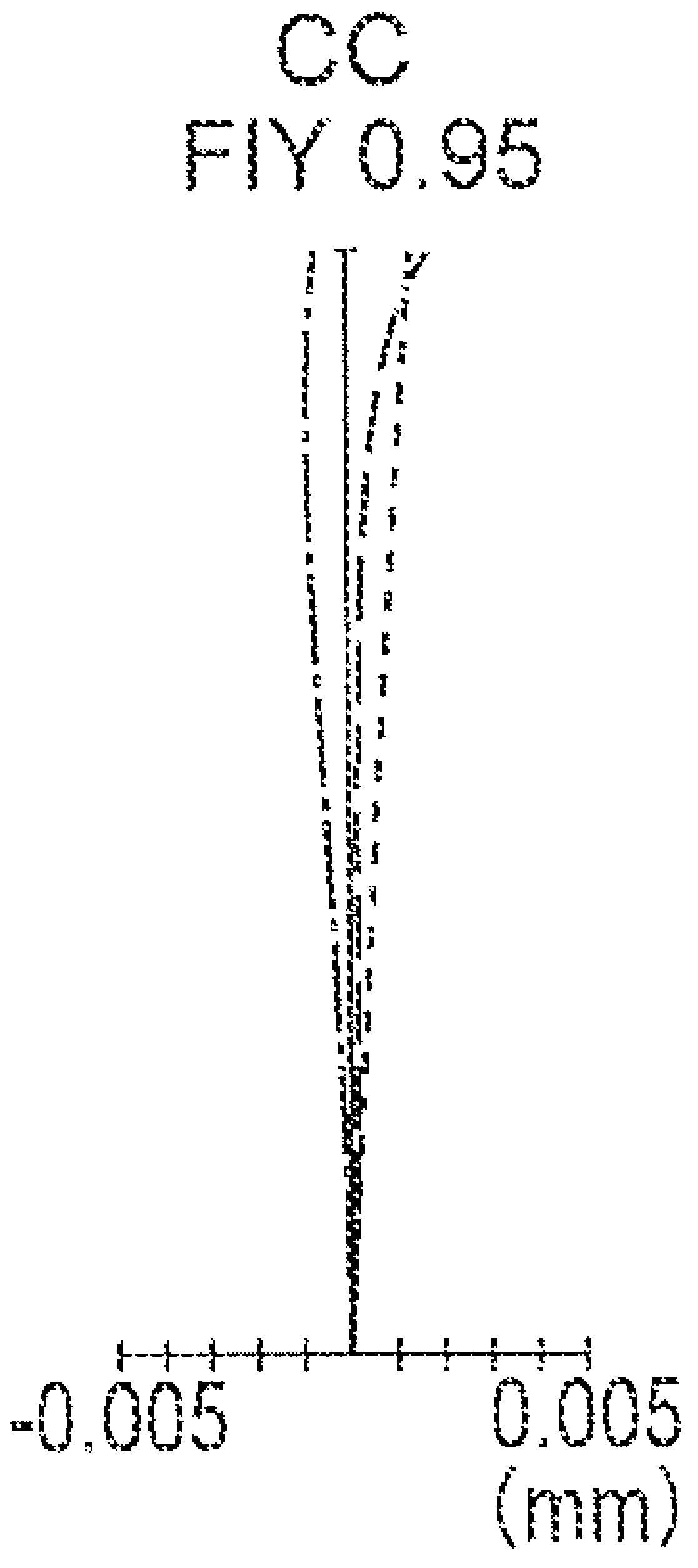


FIG. 21D

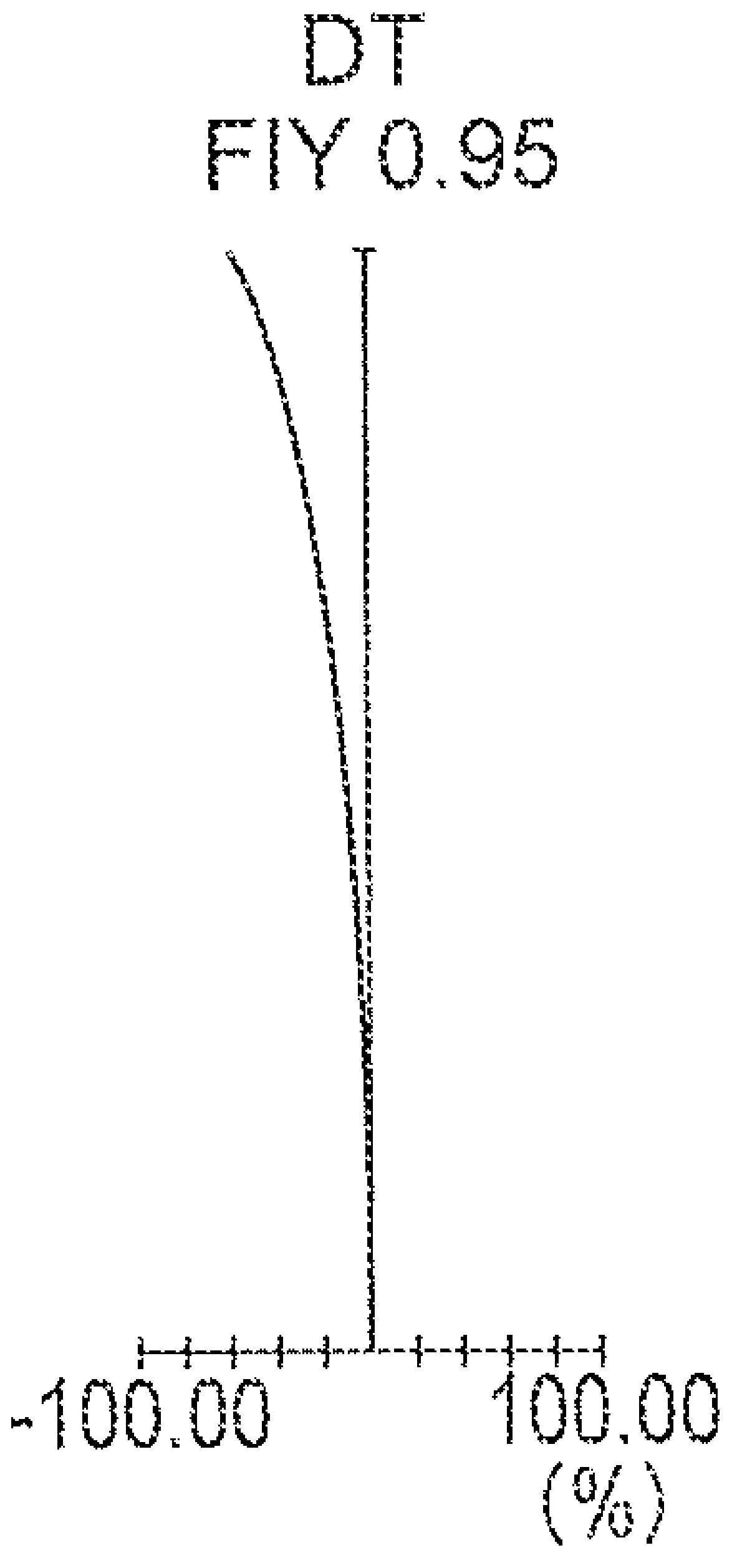


FIG. 21E

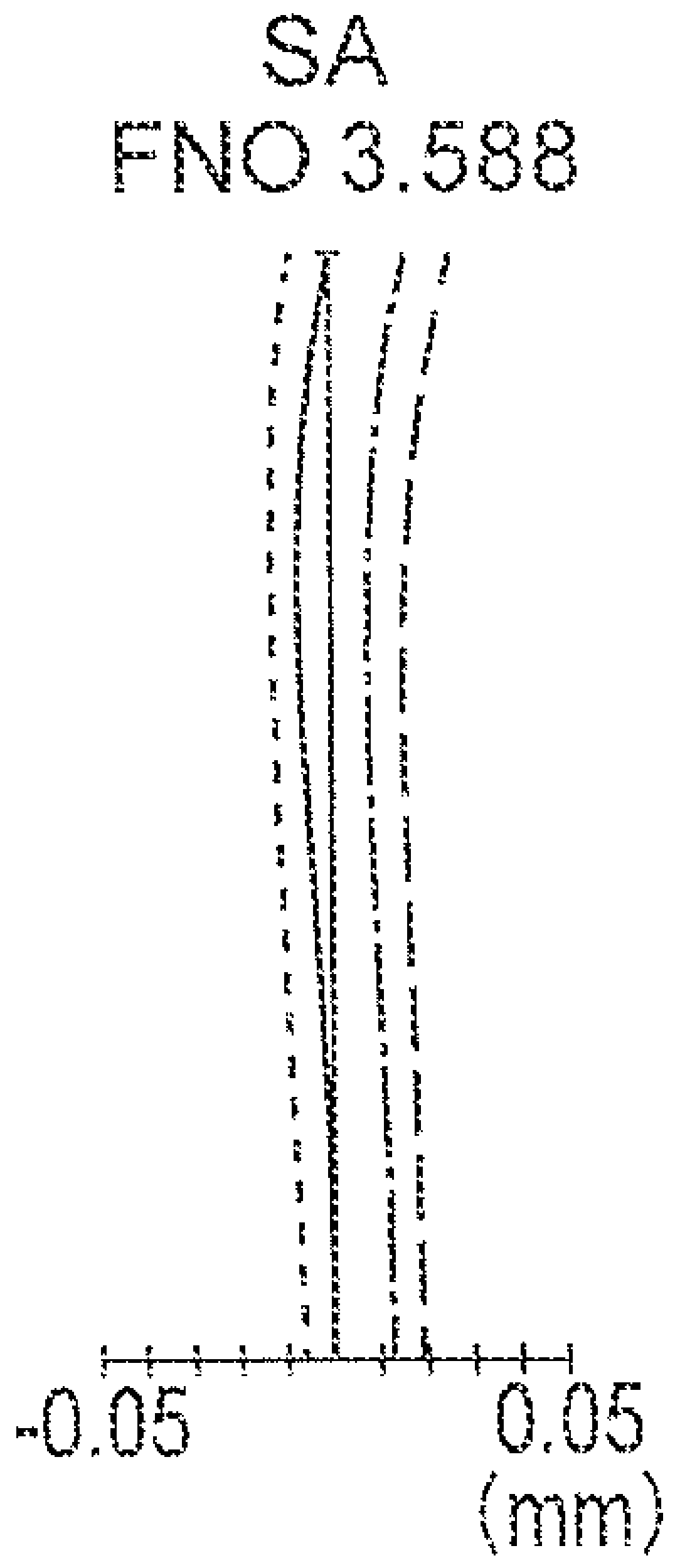


FIG. 21F

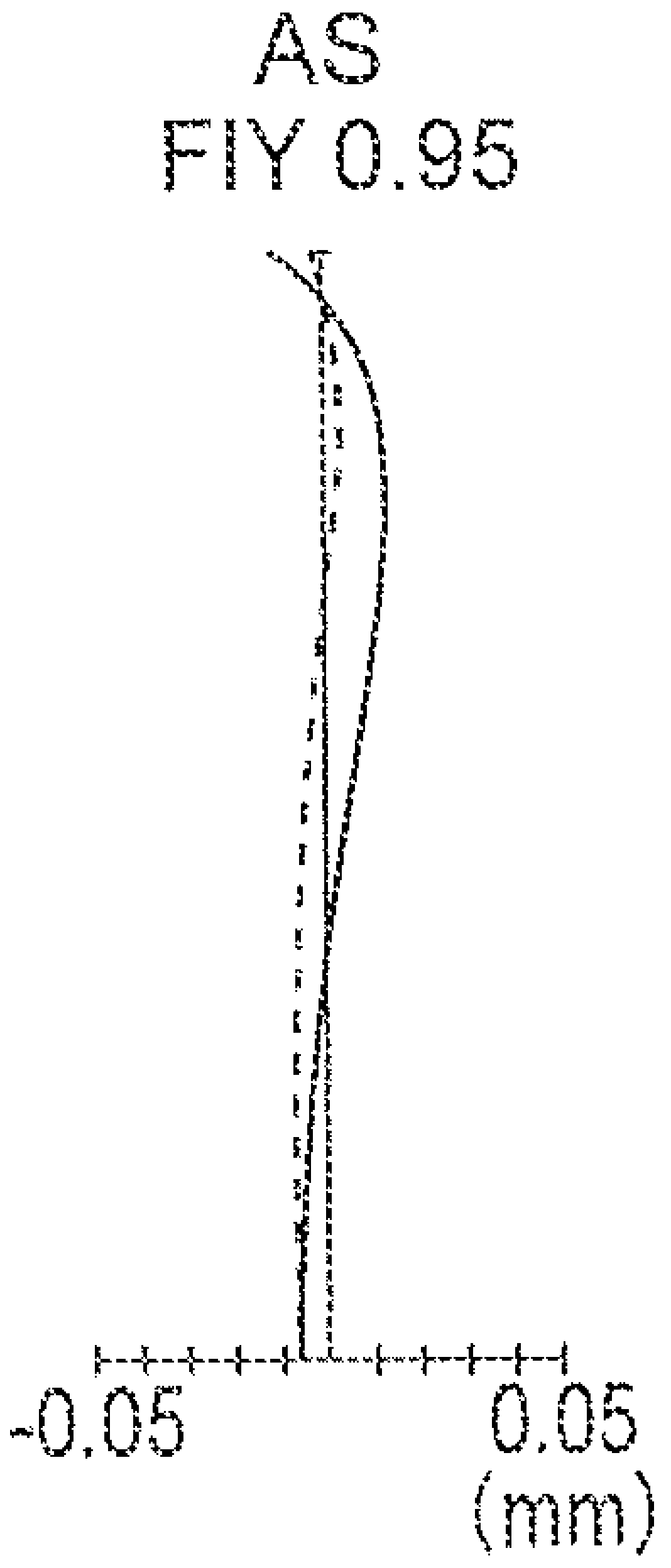


FIG. 21G

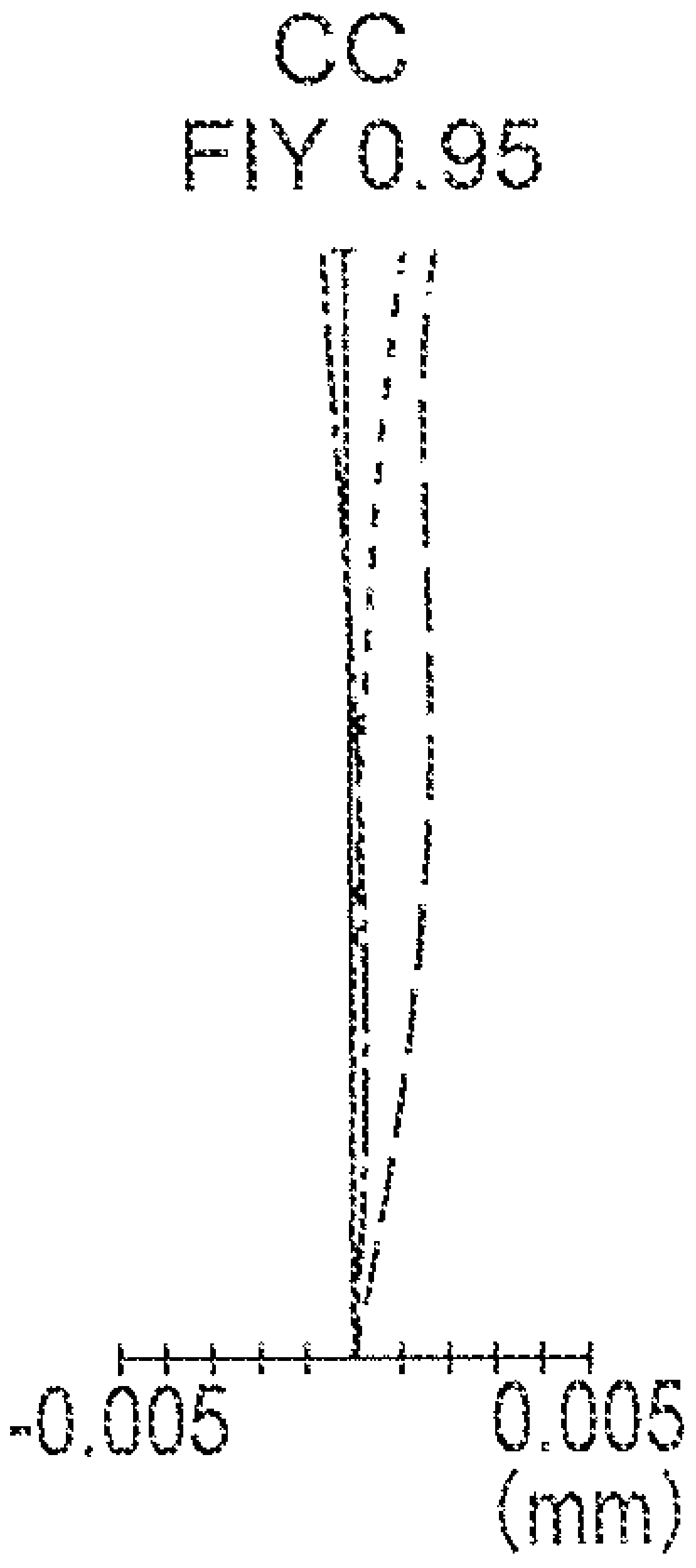


FIG. 21H

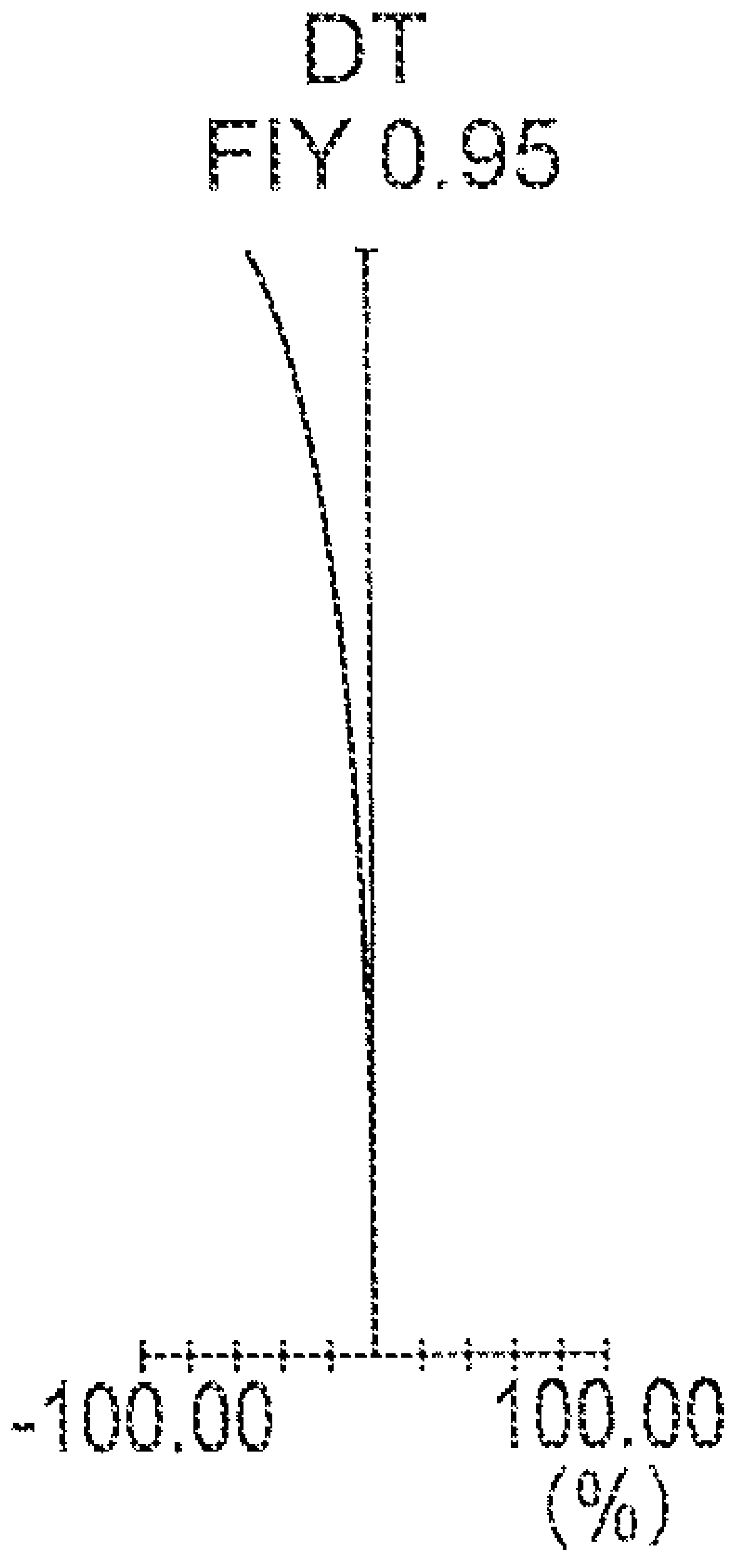


FIG. 22A

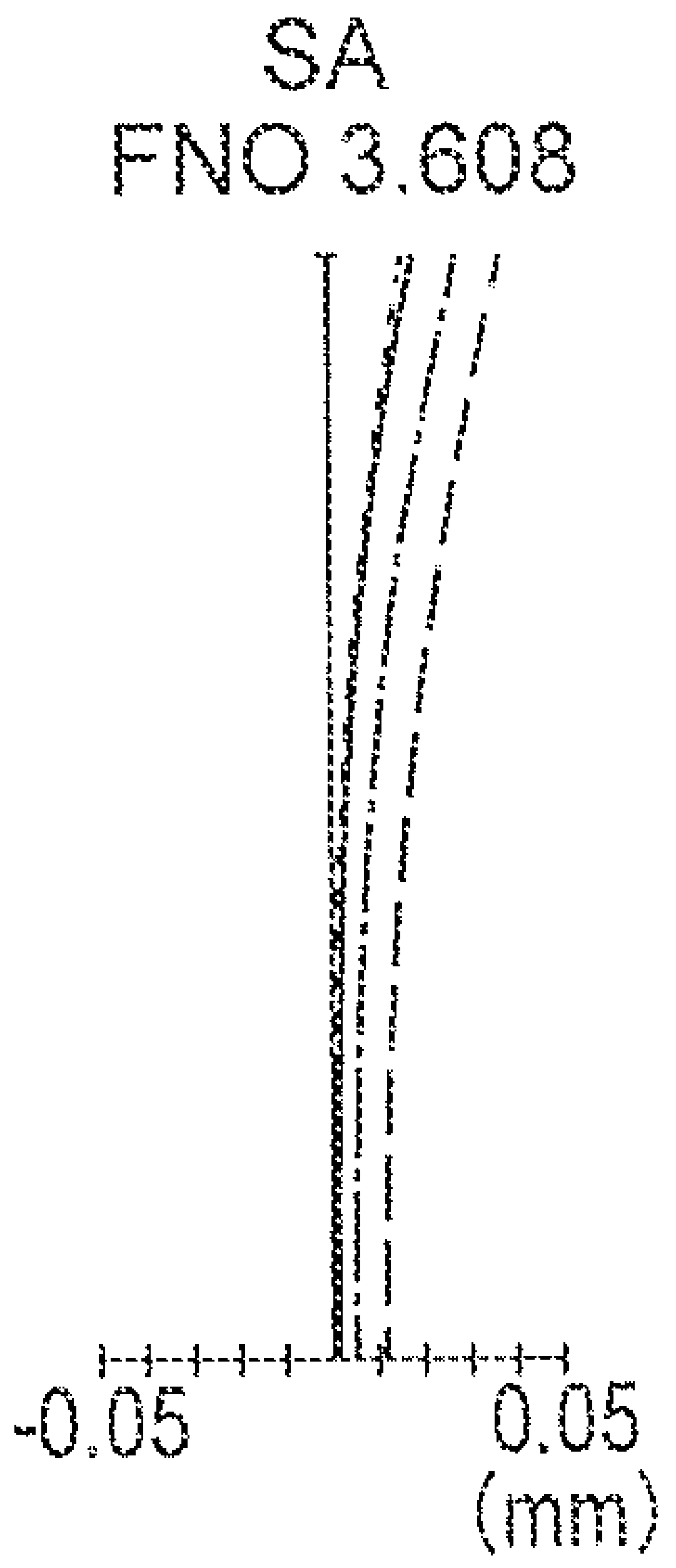


FIG. 22B

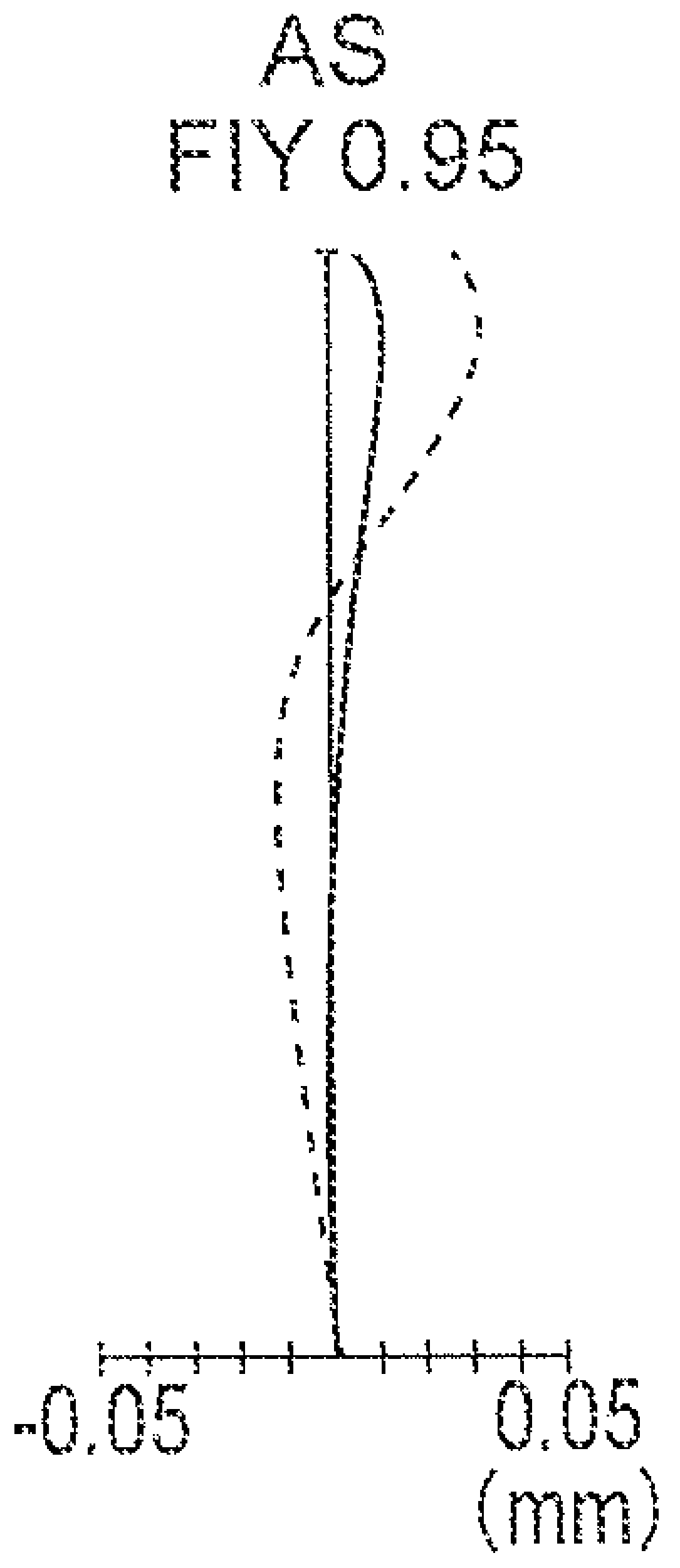


FIG. 22C

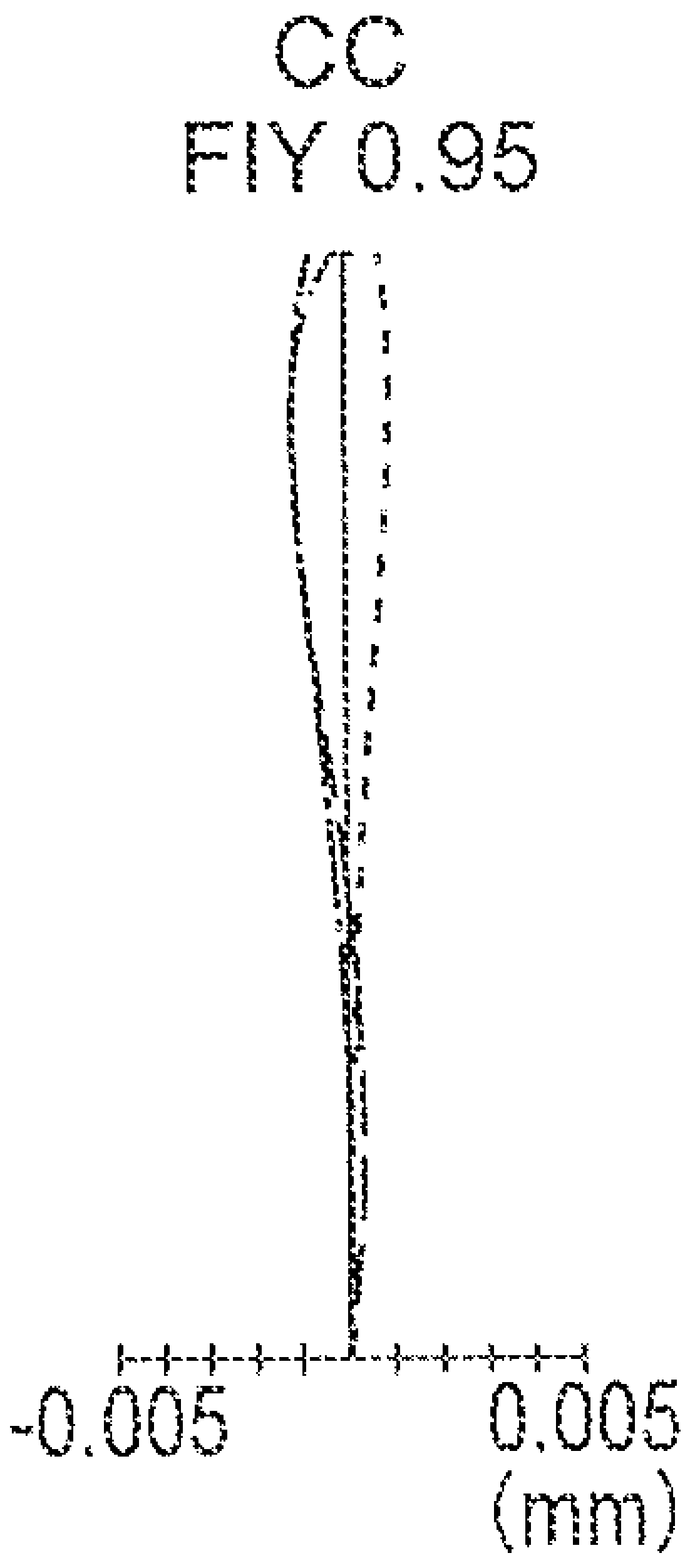


FIG. 22D

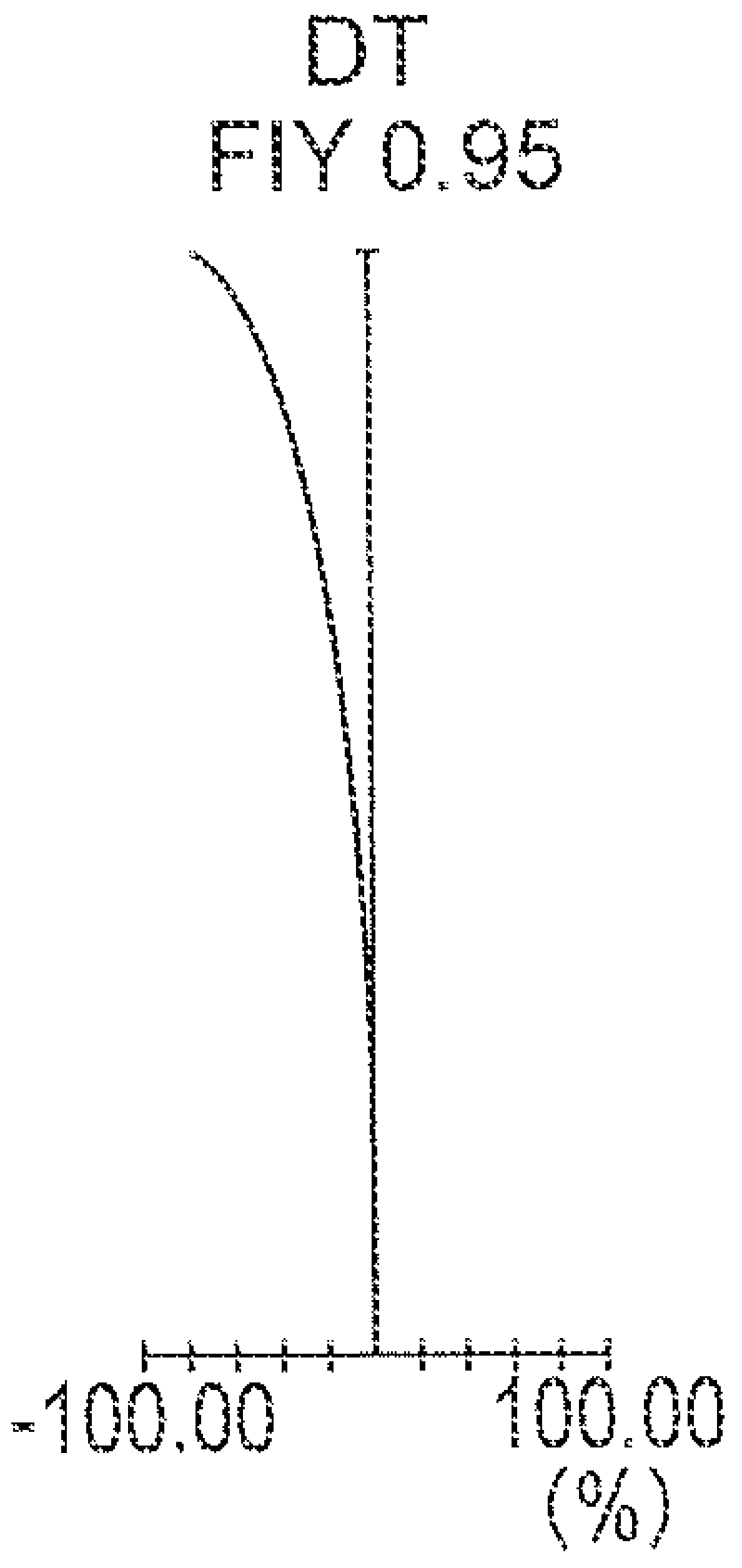


FIG. 22E

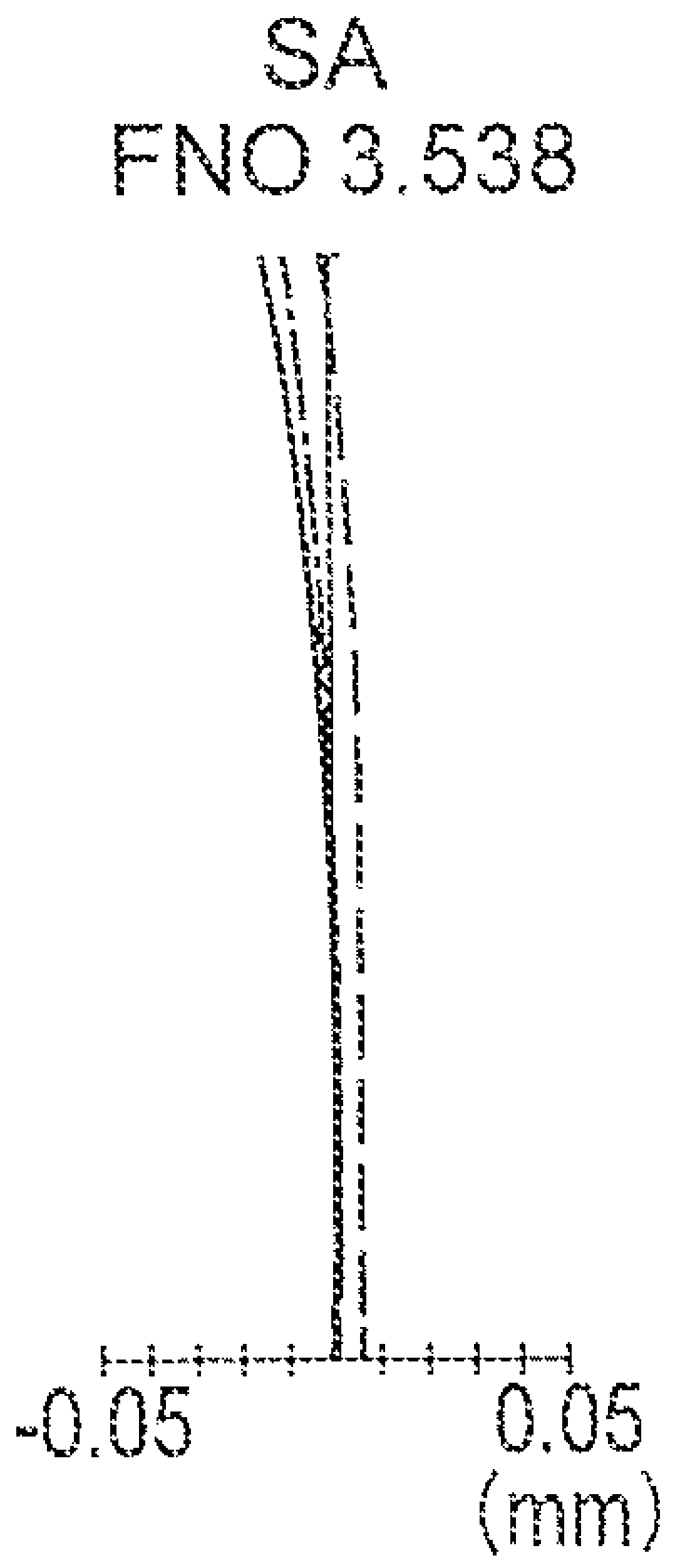


FIG. 22F

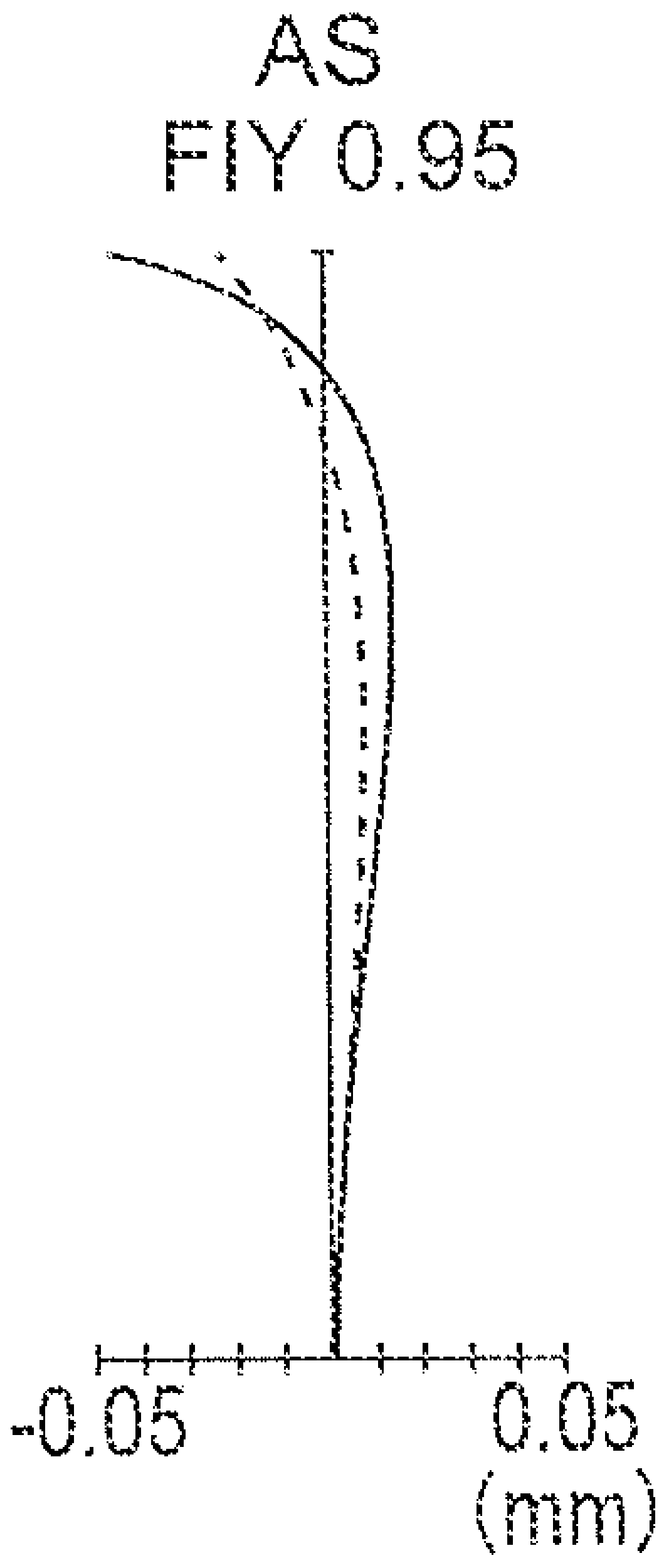


FIG. 22G

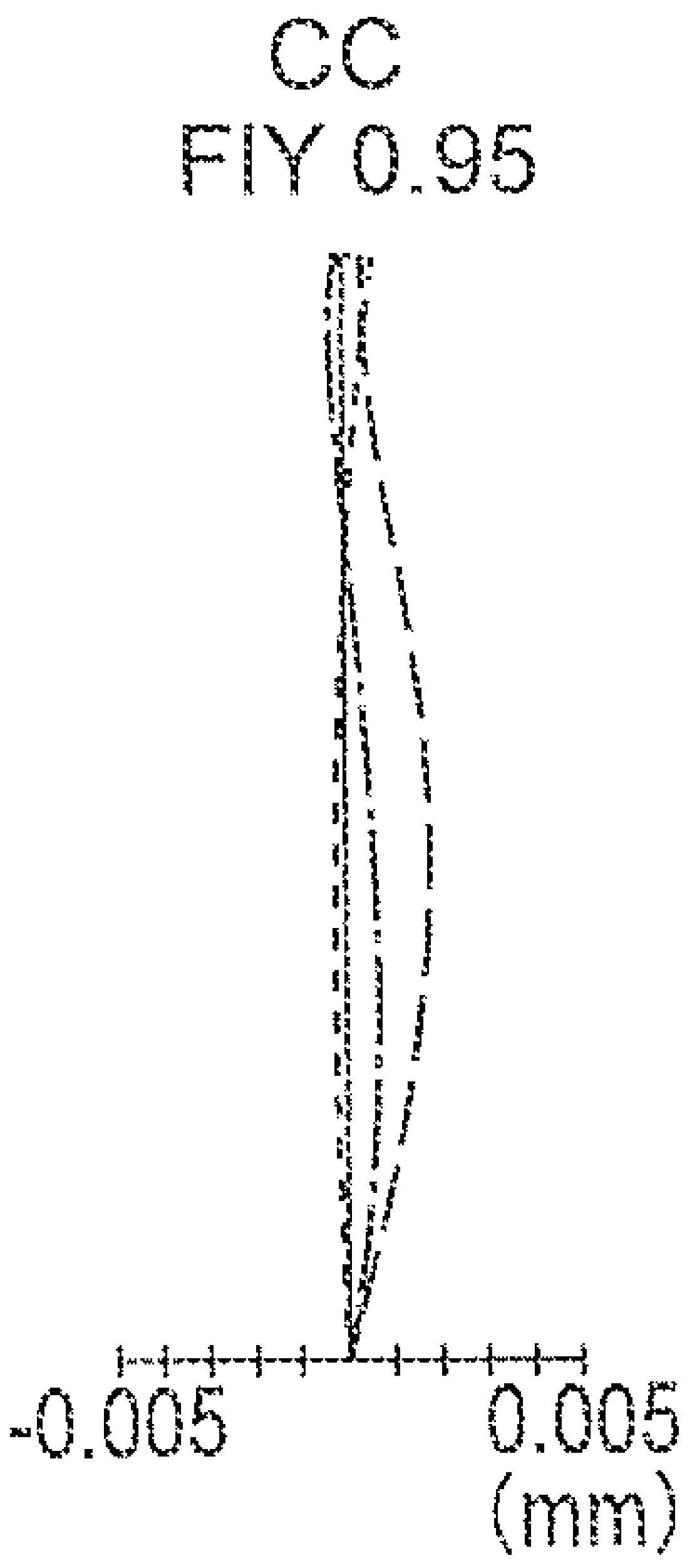


FIG. 22H

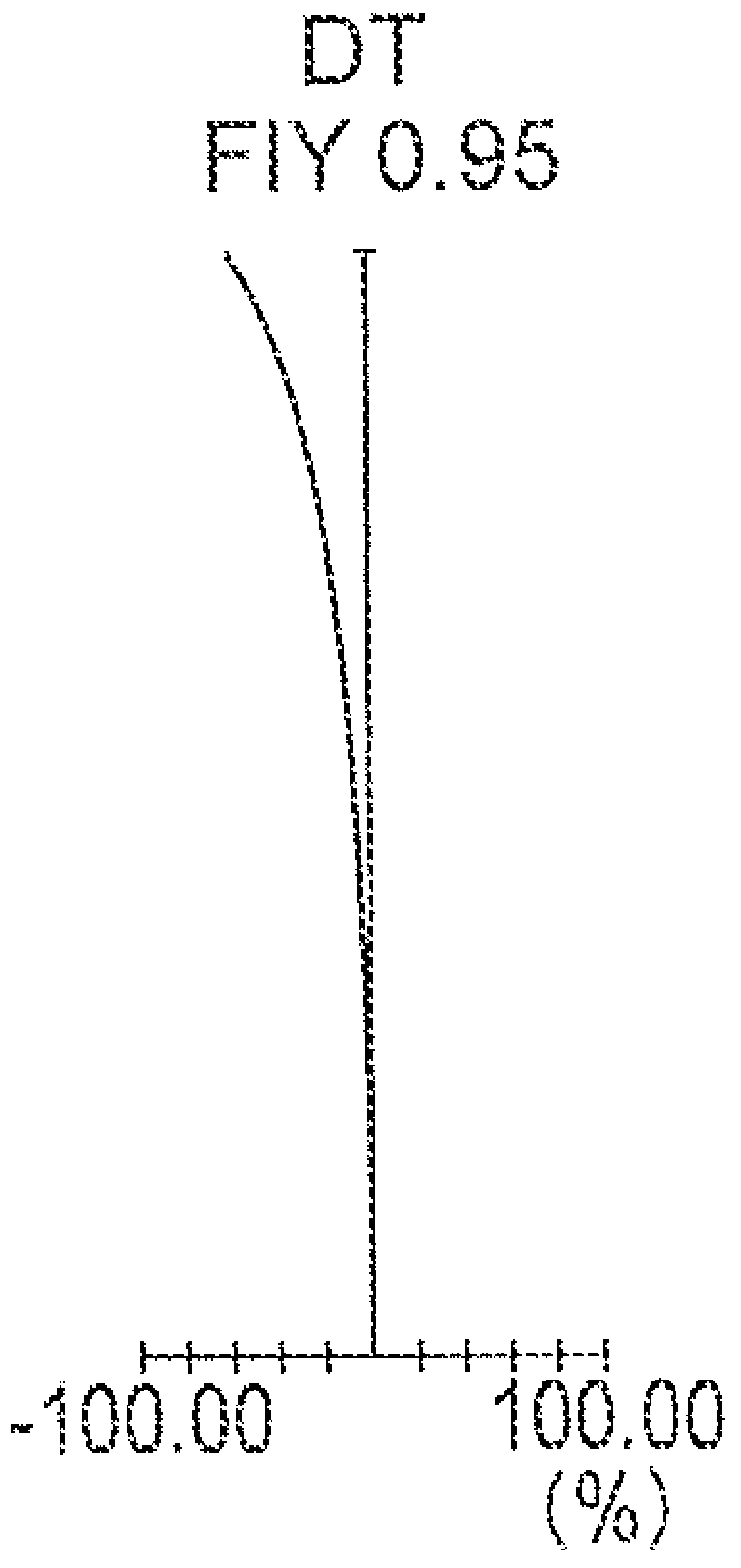


FIG. 23A

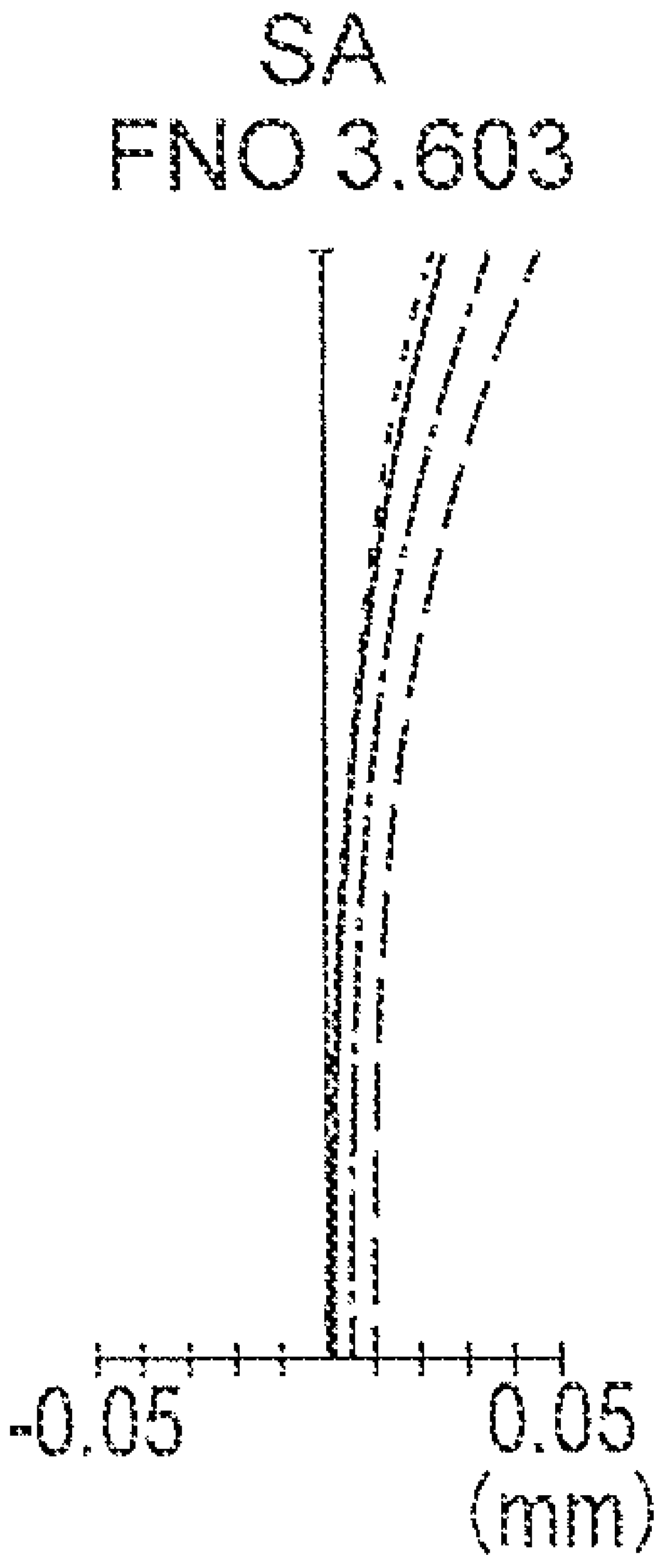


FIG. 23B

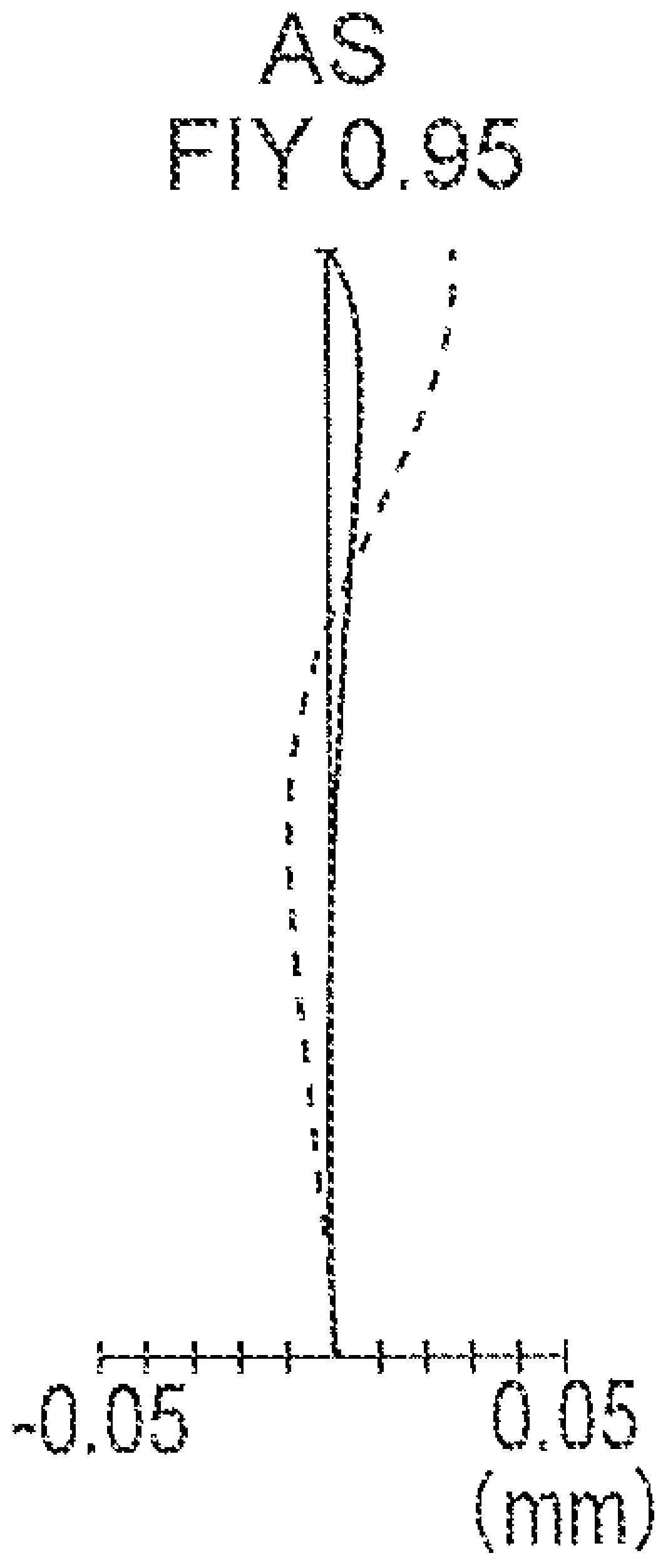


FIG. 23C

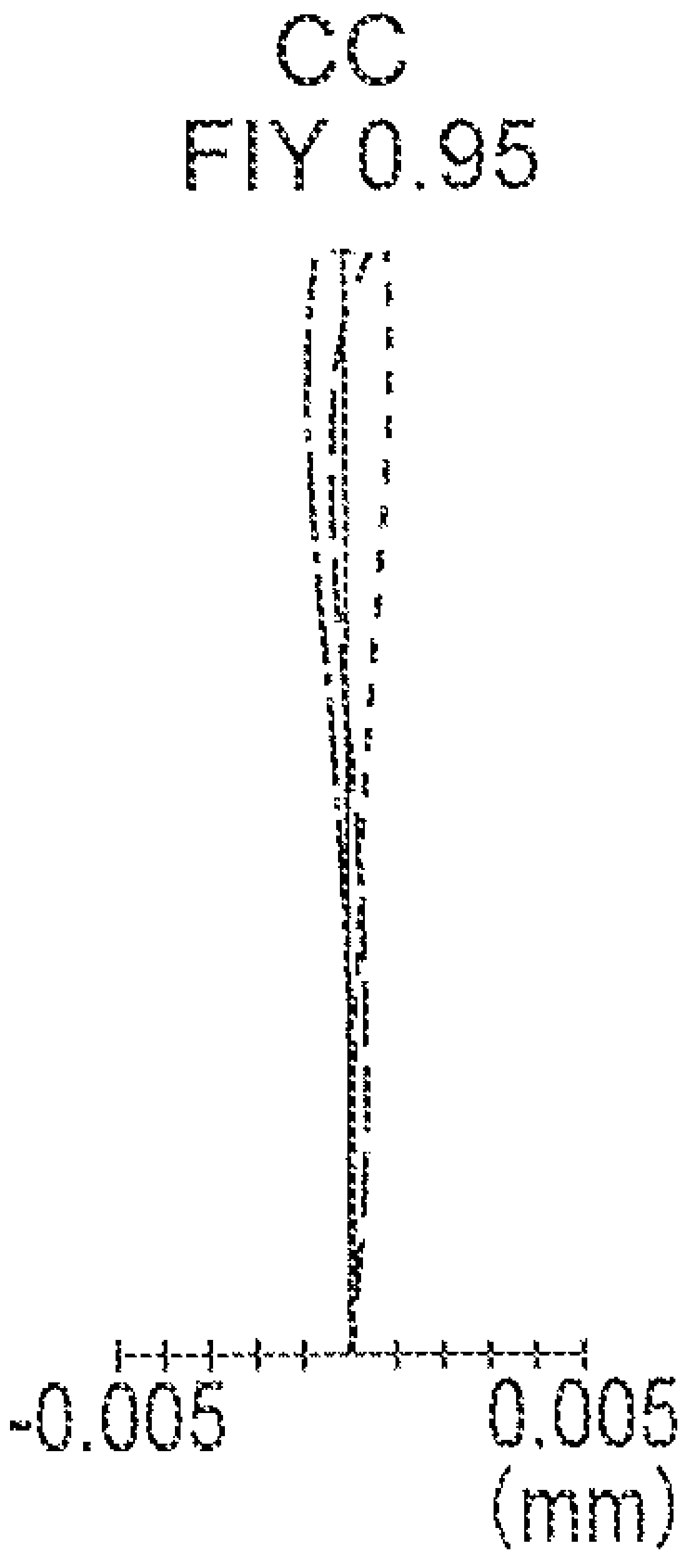


FIG. 23D

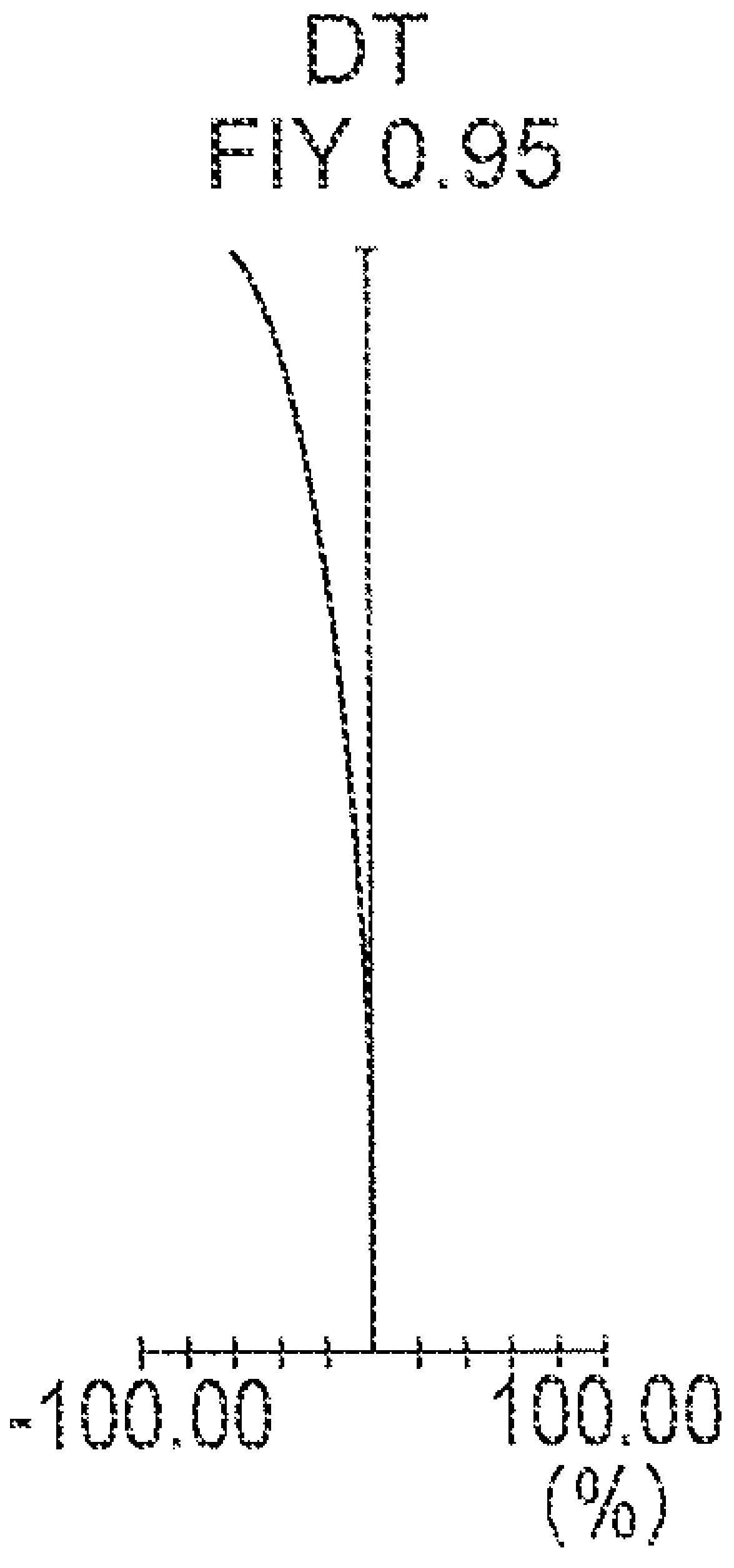


FIG. 23E

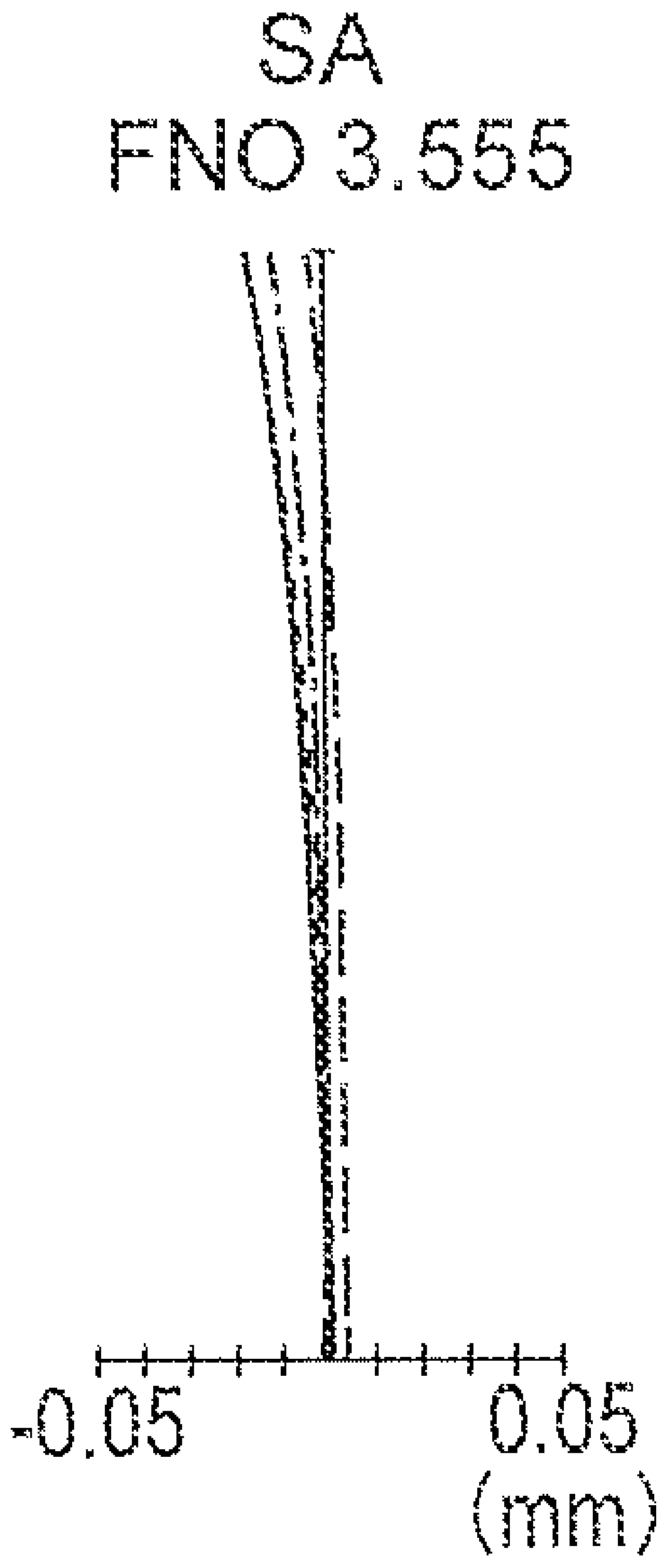


FIG. 23F

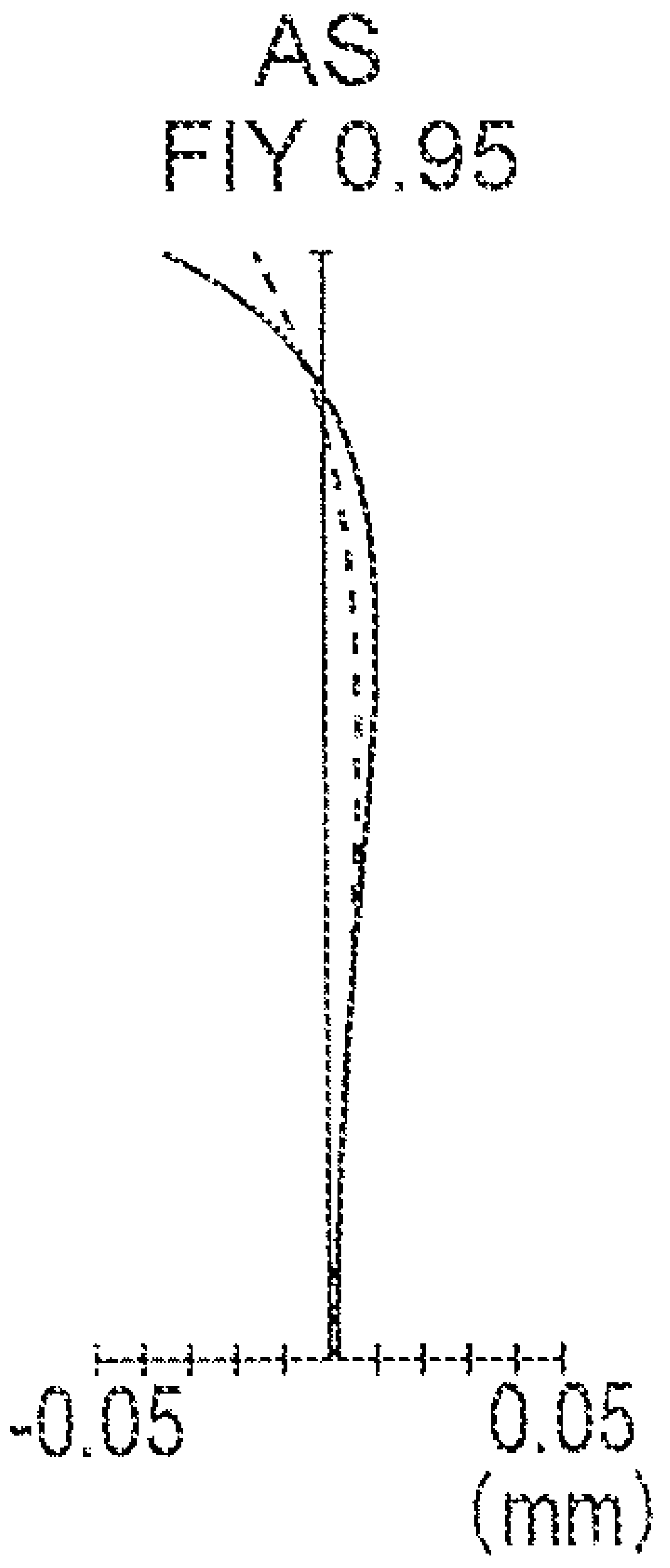


FIG. 23G

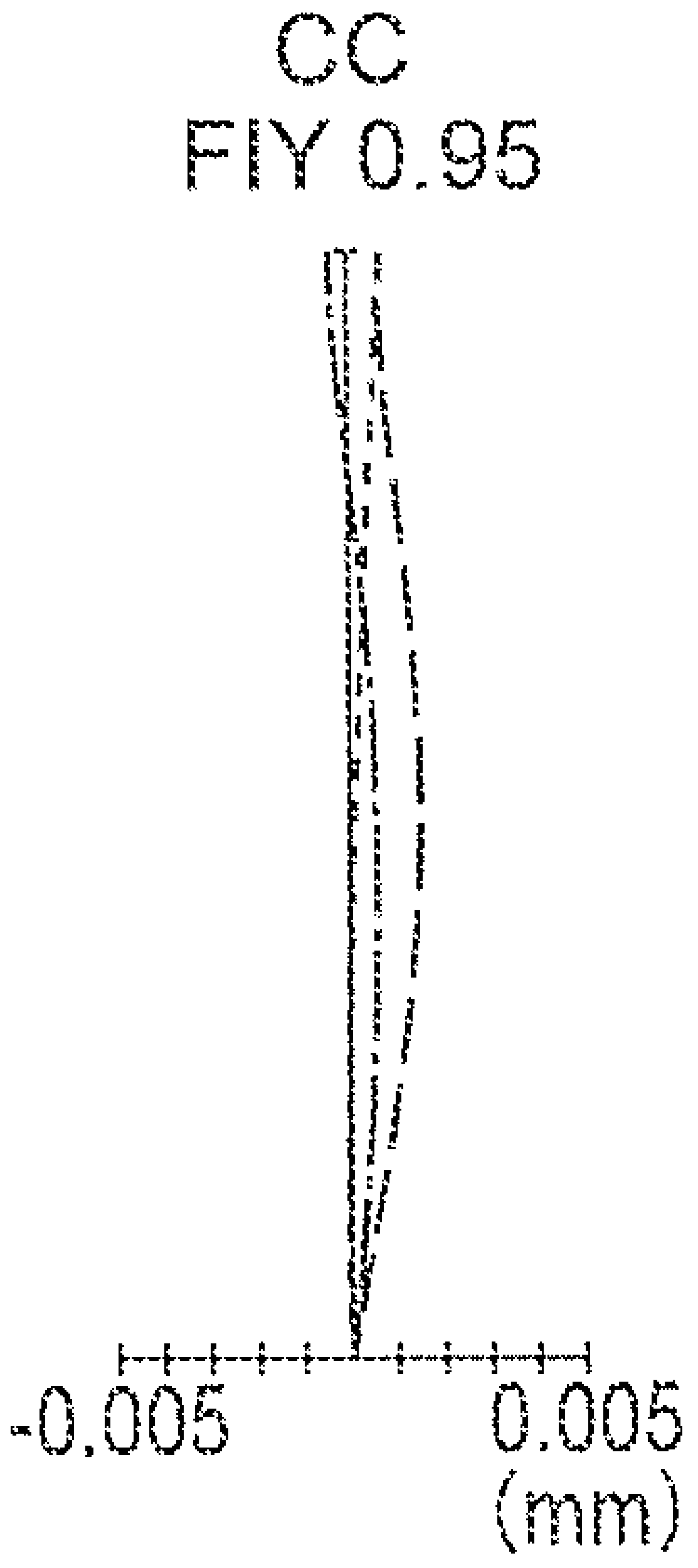


FIG. 23H

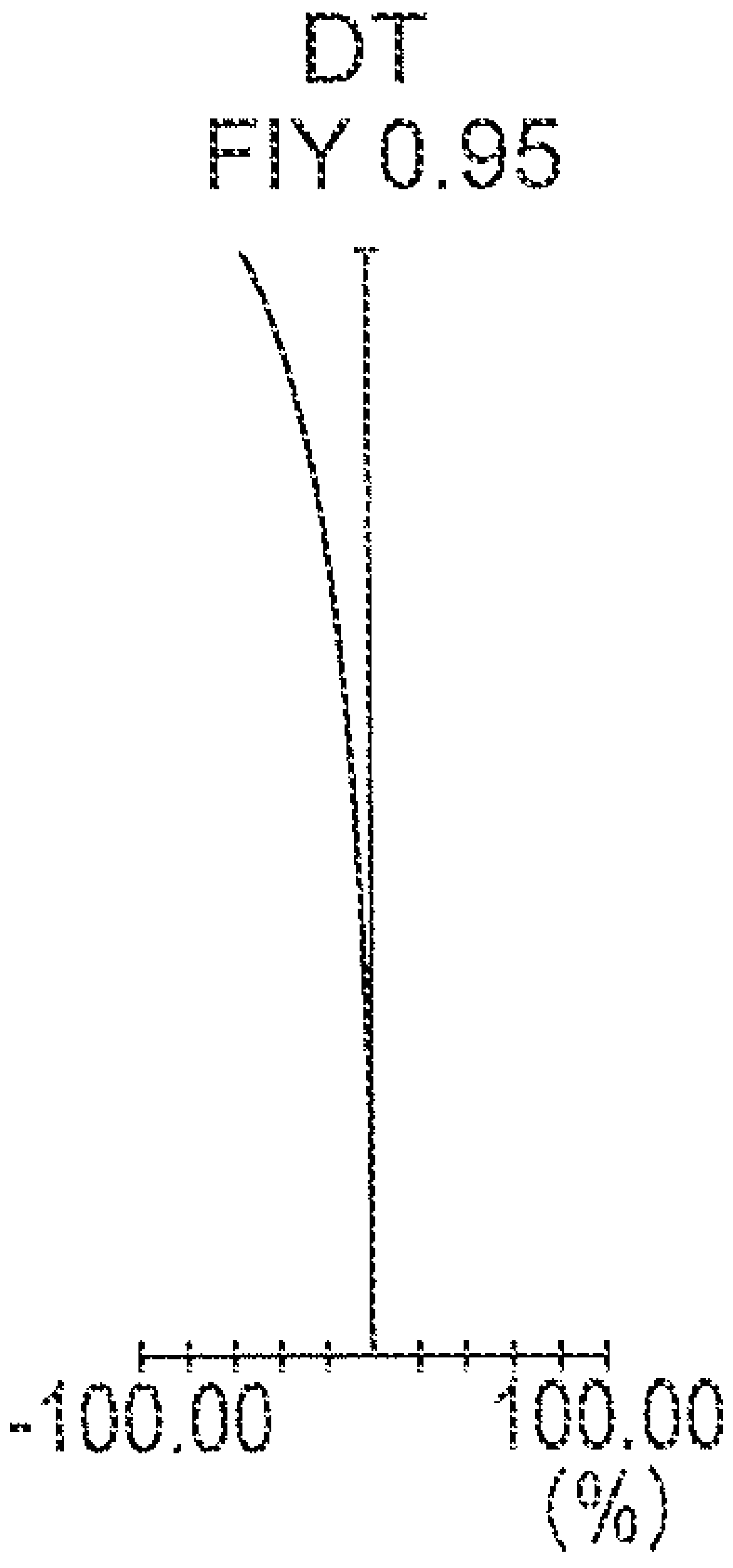


FIG. 24A

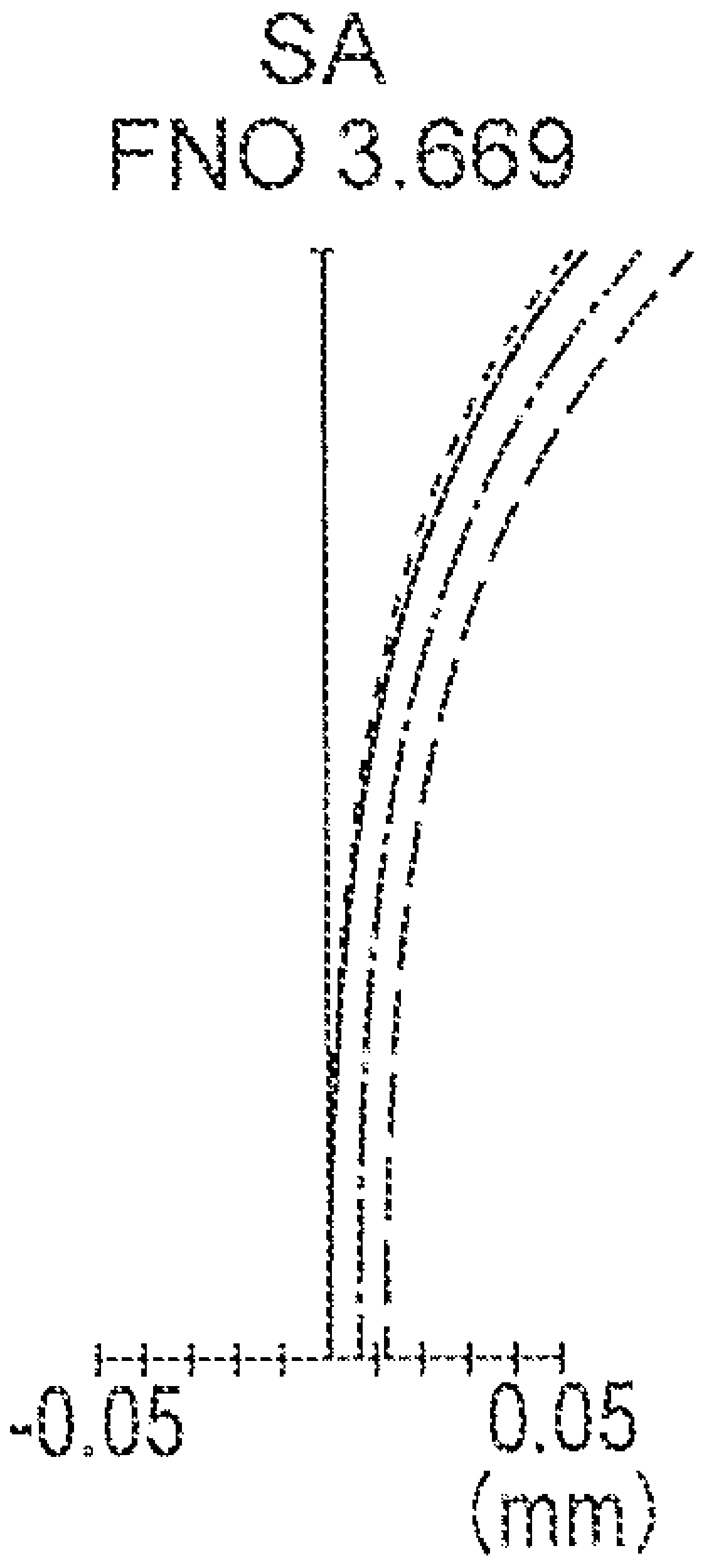


FIG. 24B

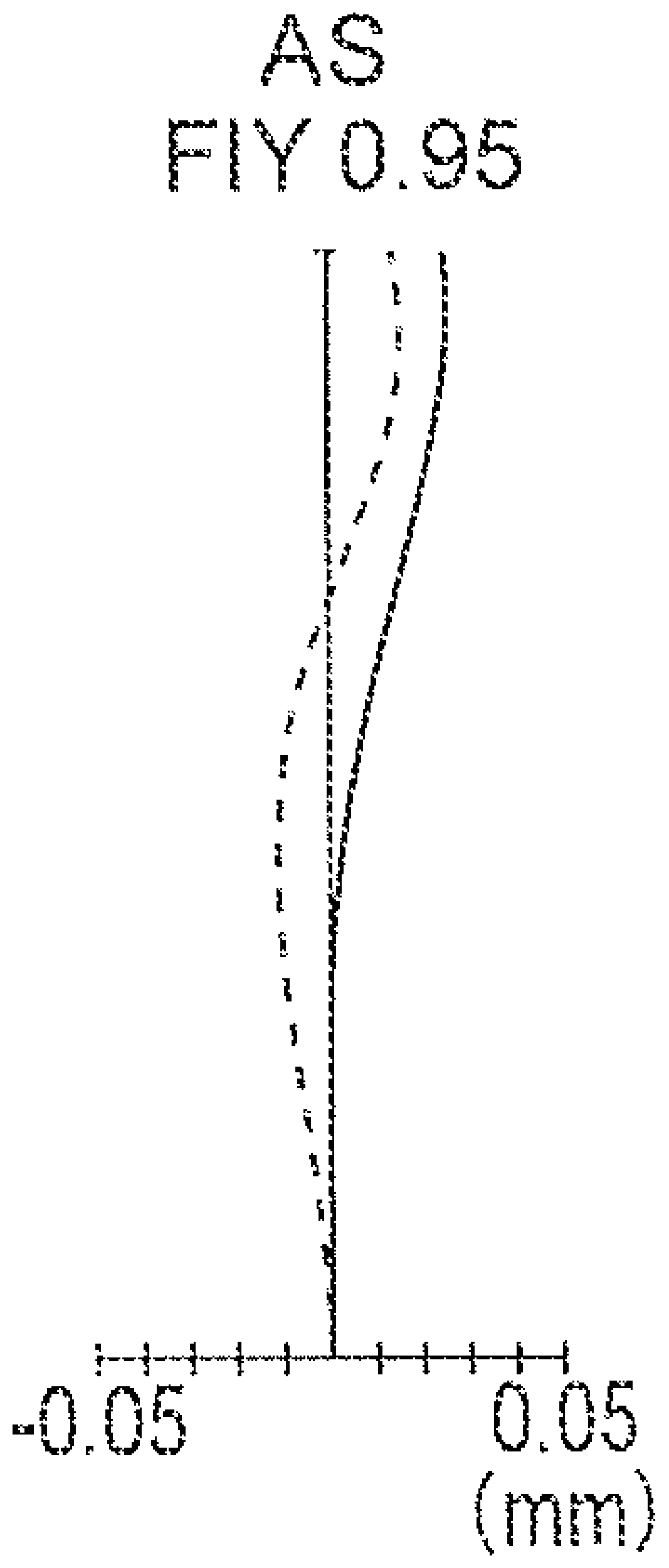


FIG. 24C

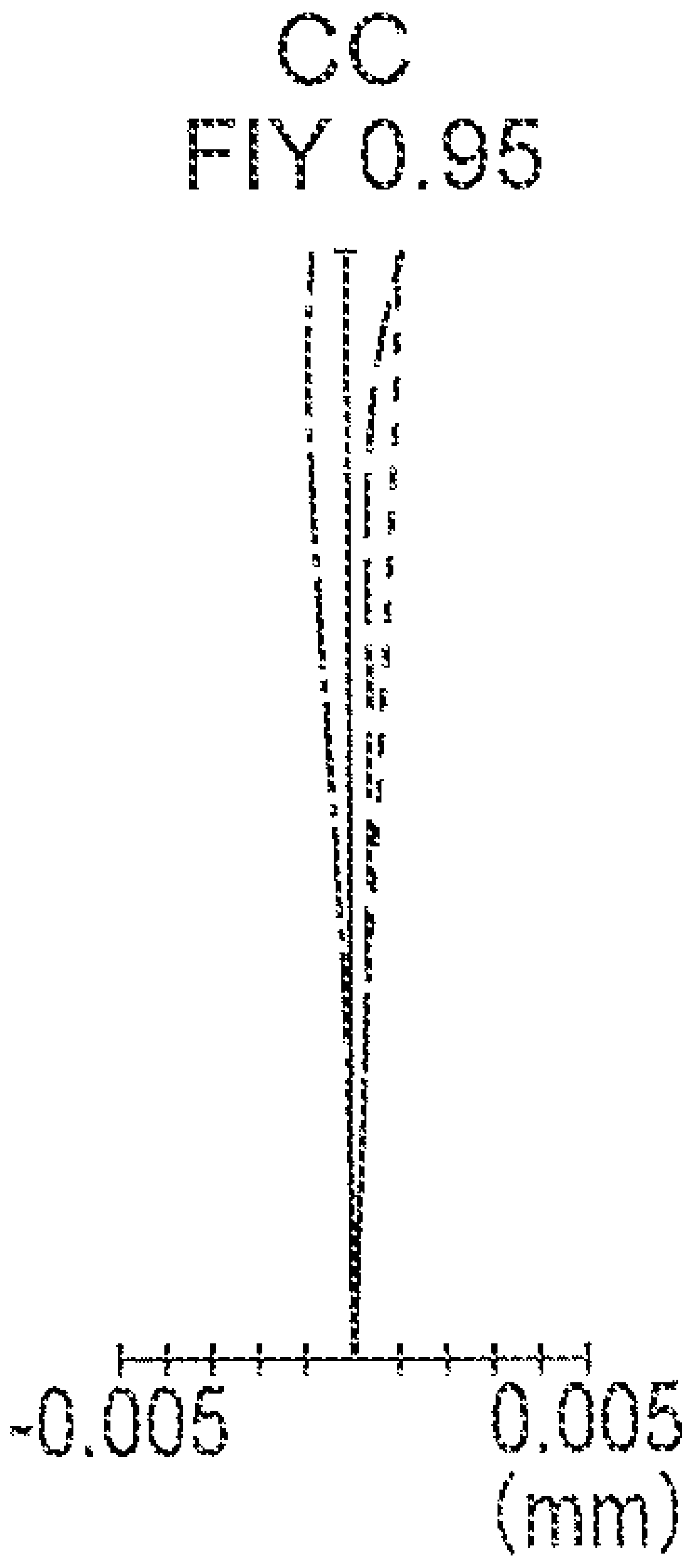


FIG. 24D

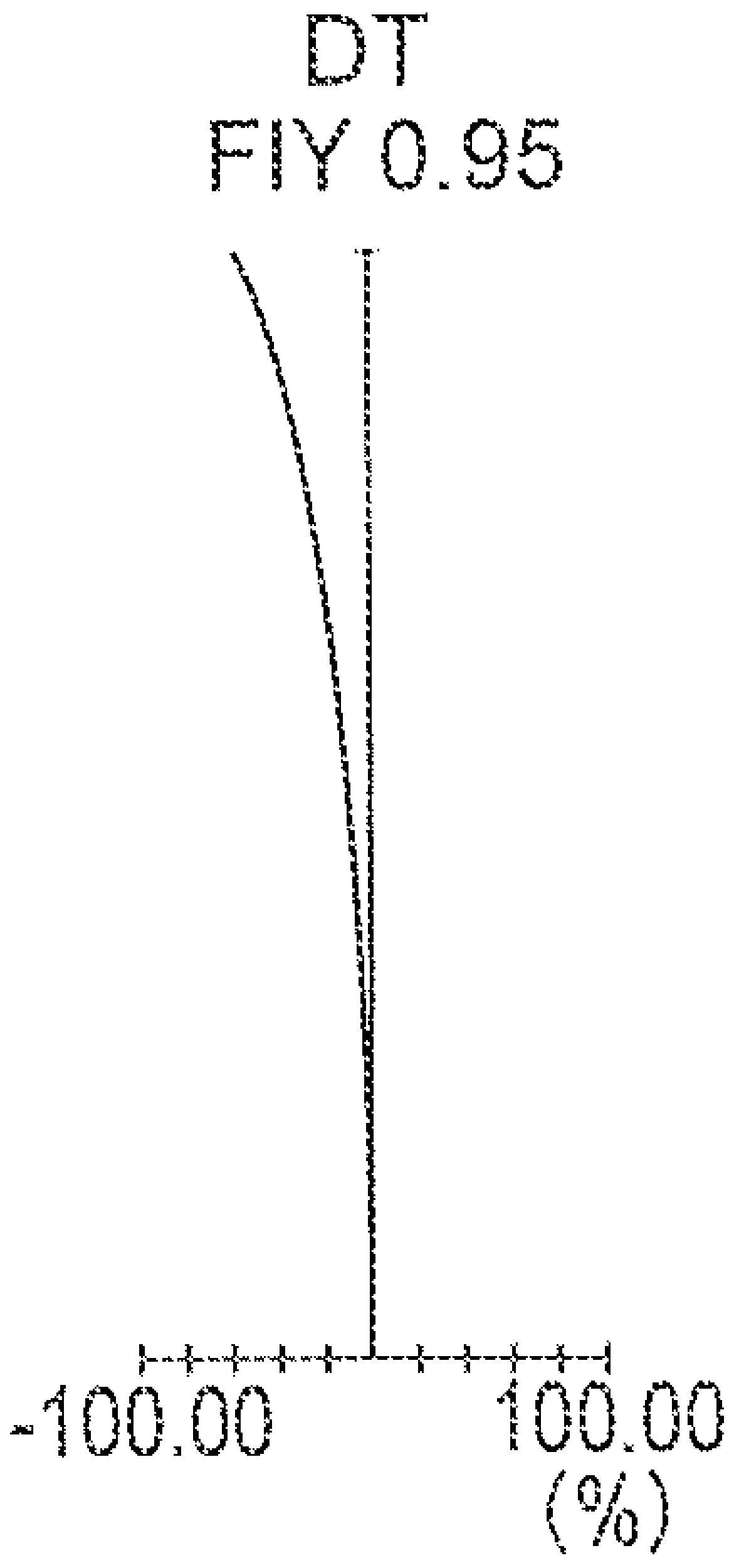


FIG. 24E

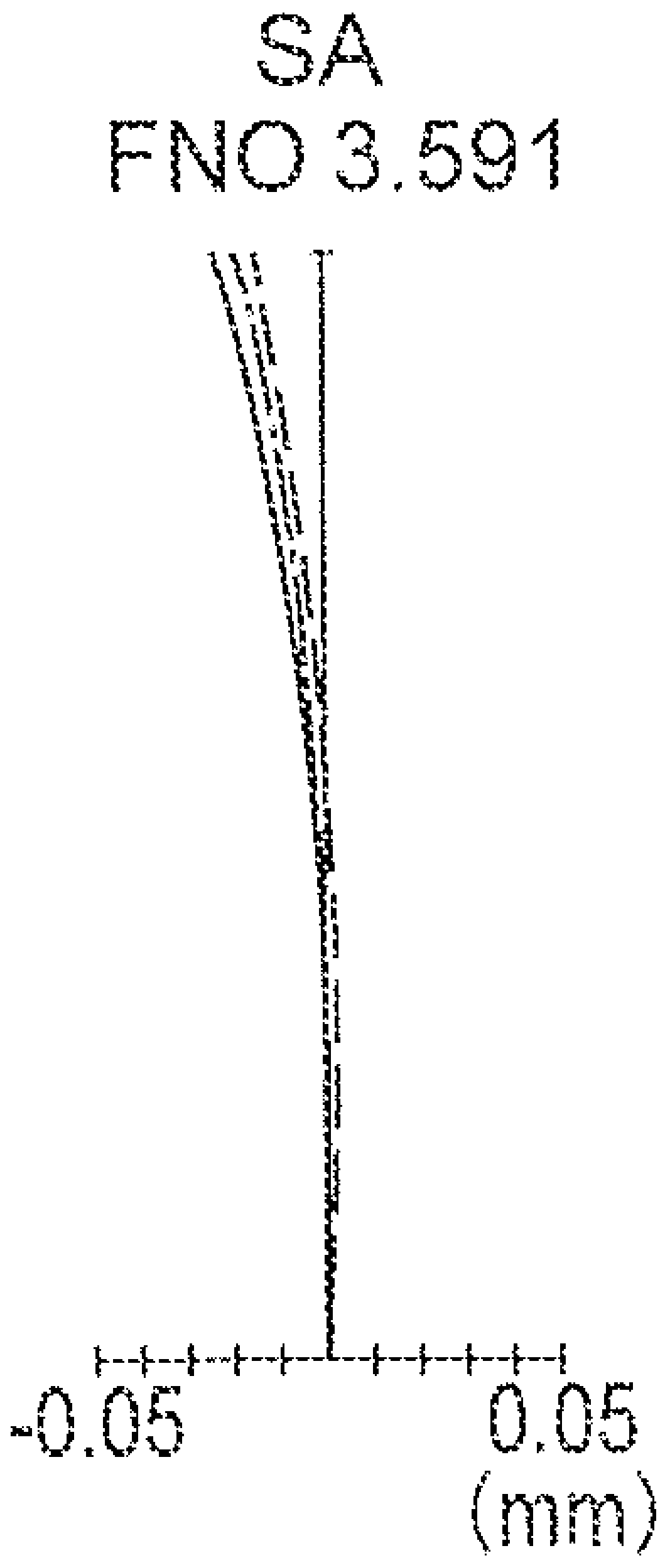


FIG. 24F

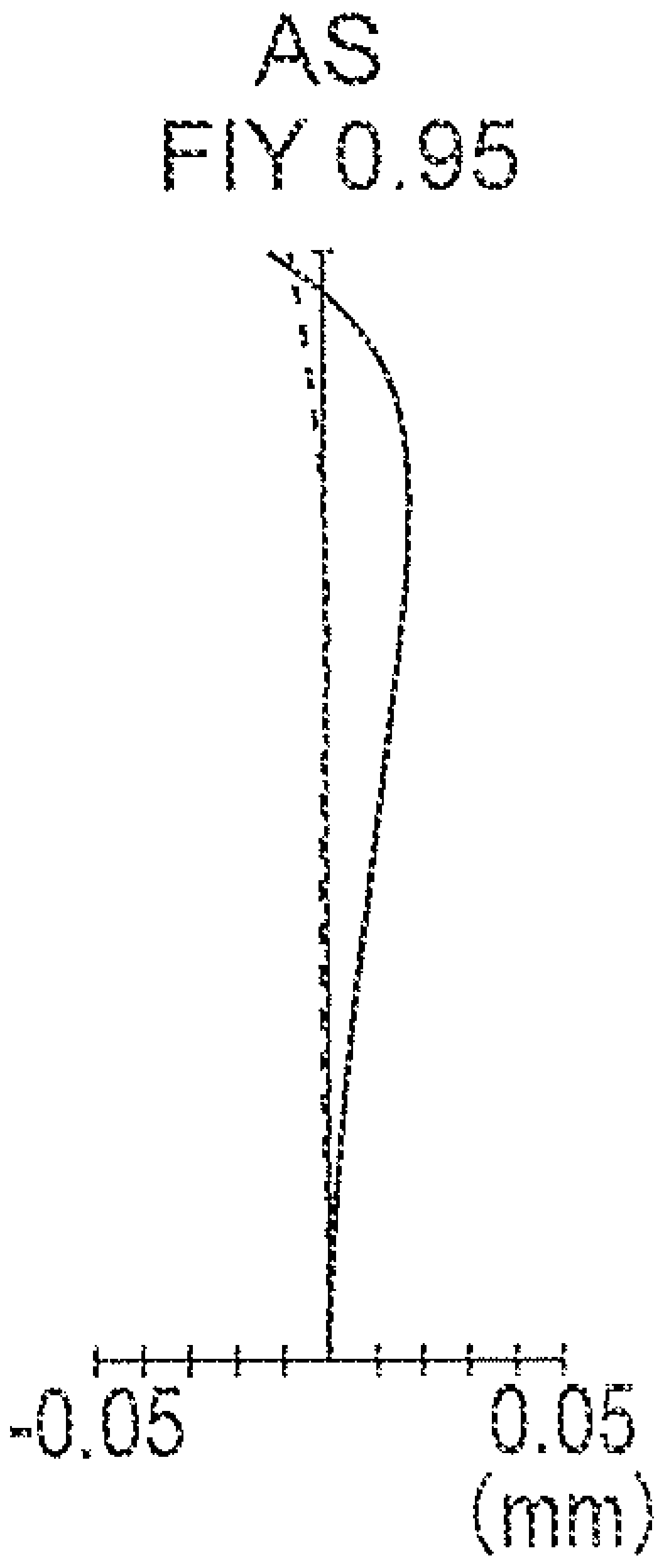


FIG. 24G

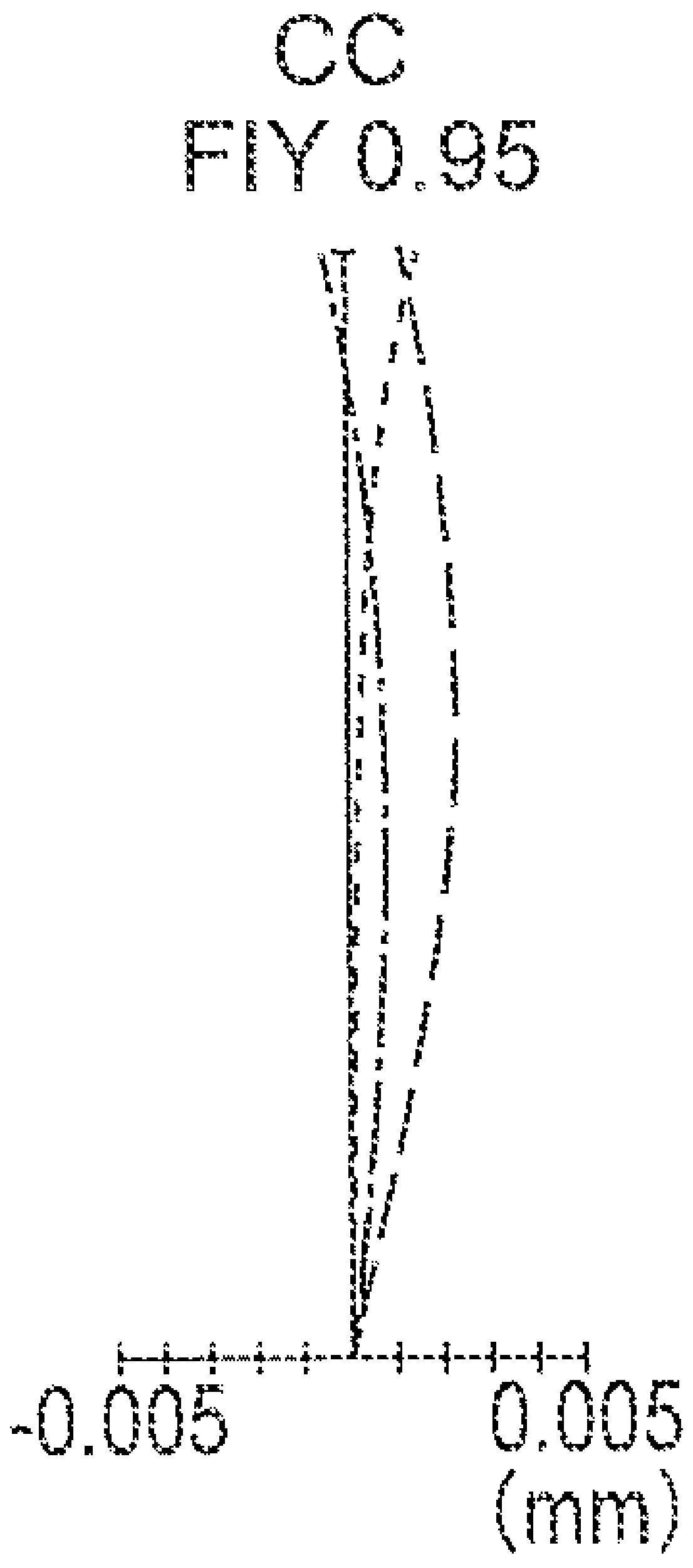


FIG. 24H

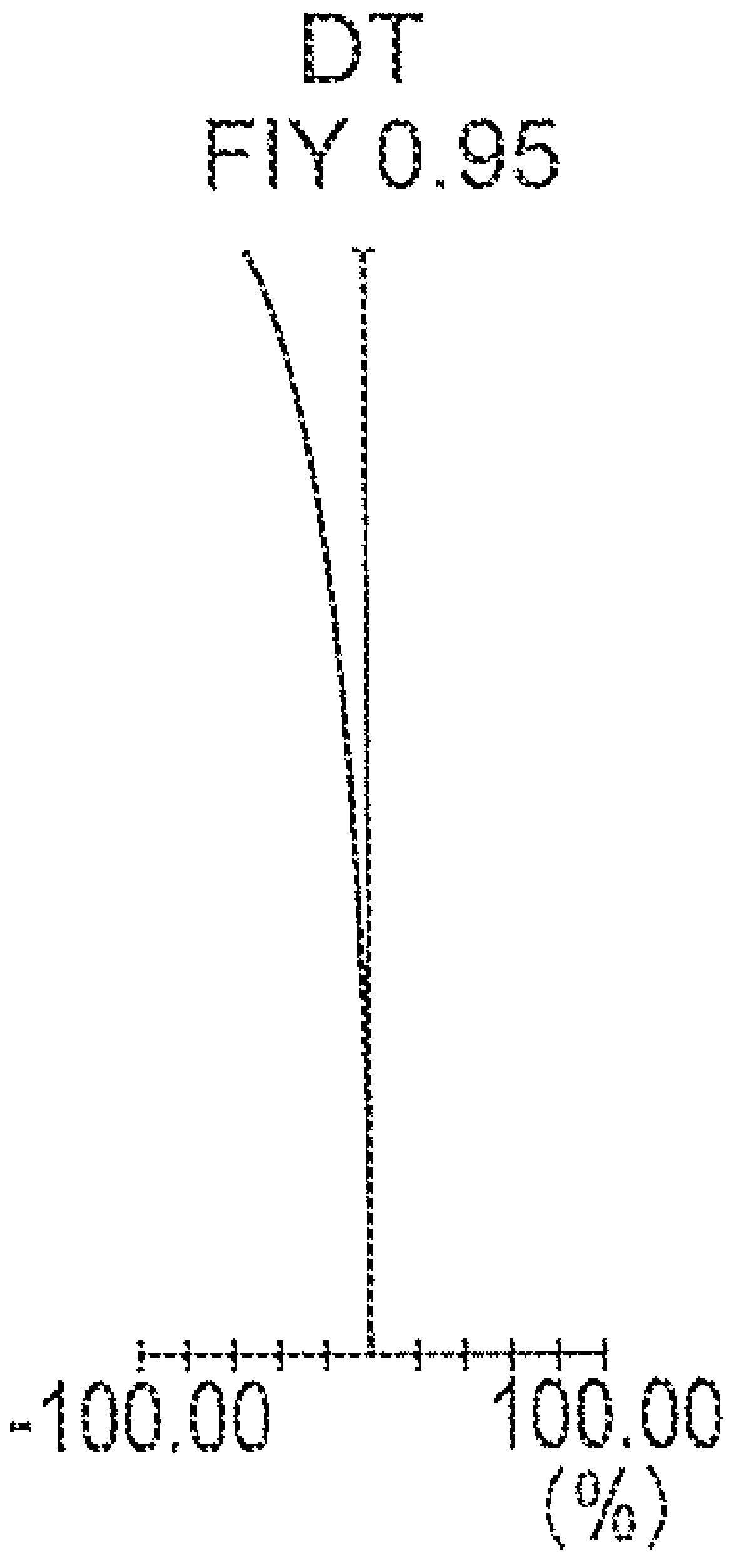


FIG. 25A

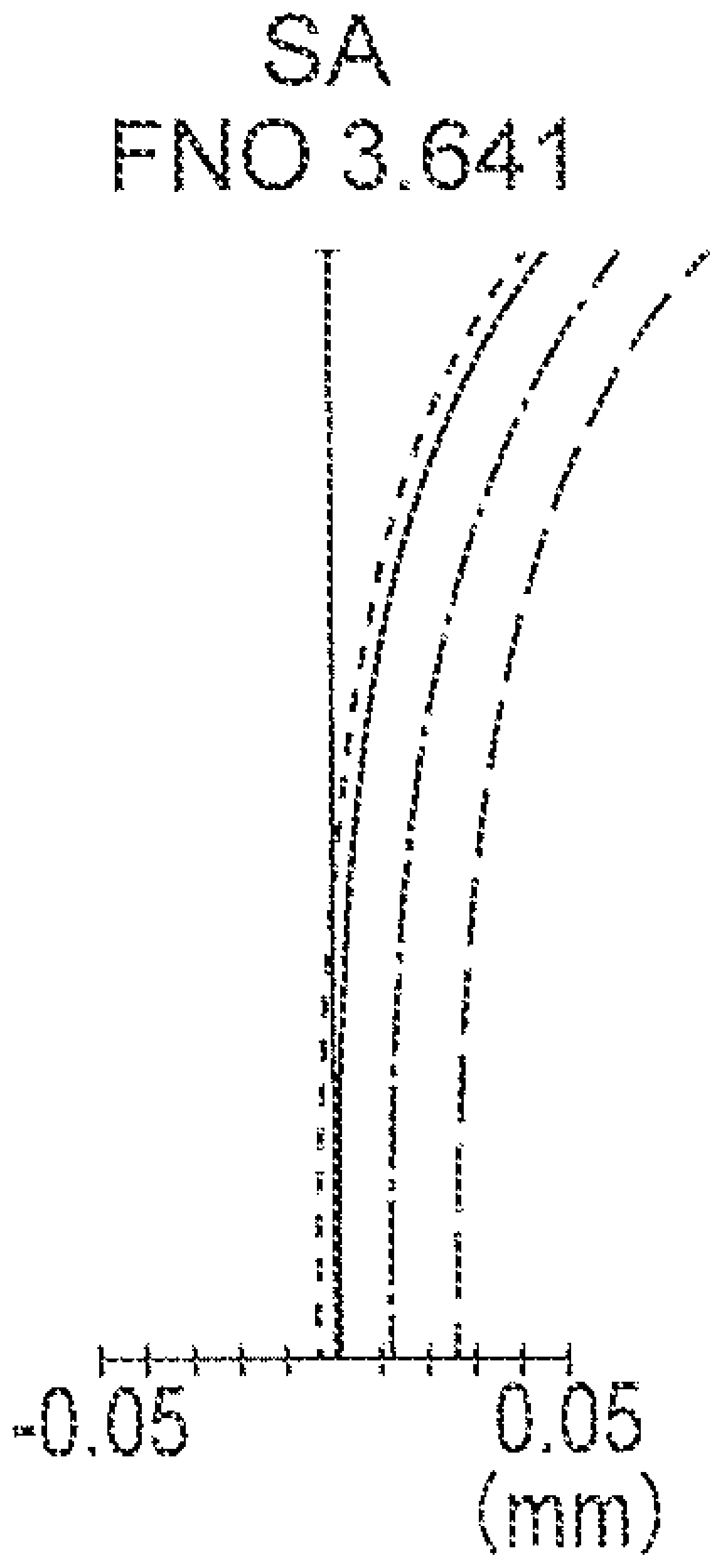


FIG. 25B

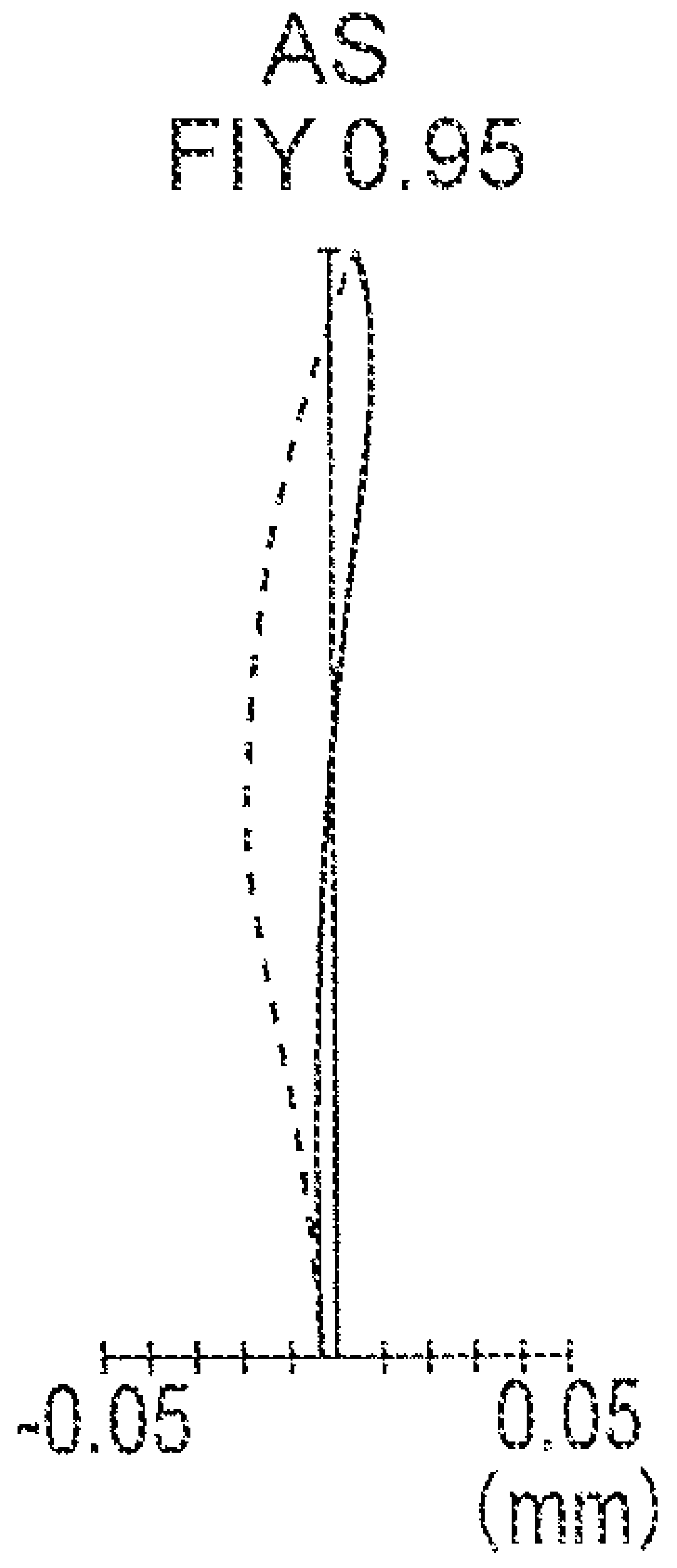


FIG. 25C

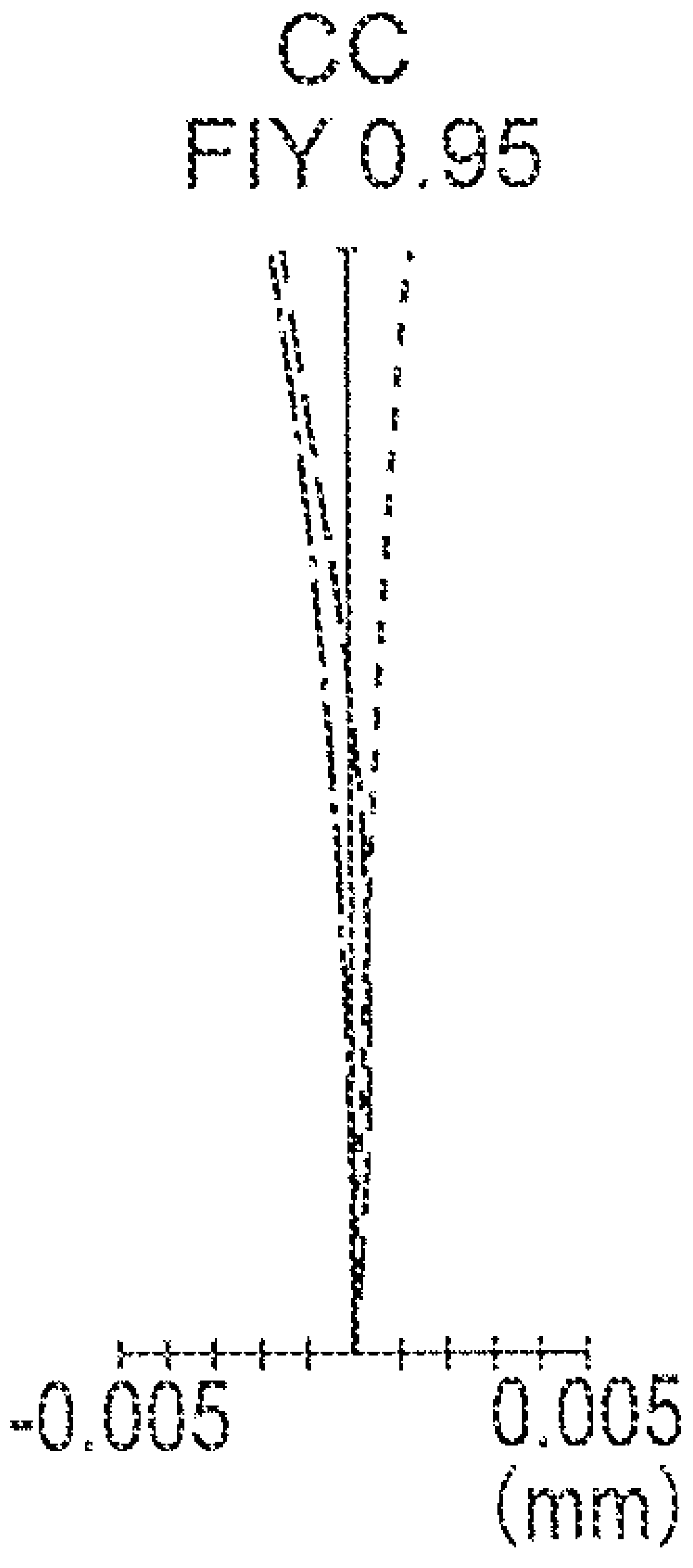


FIG. 25D

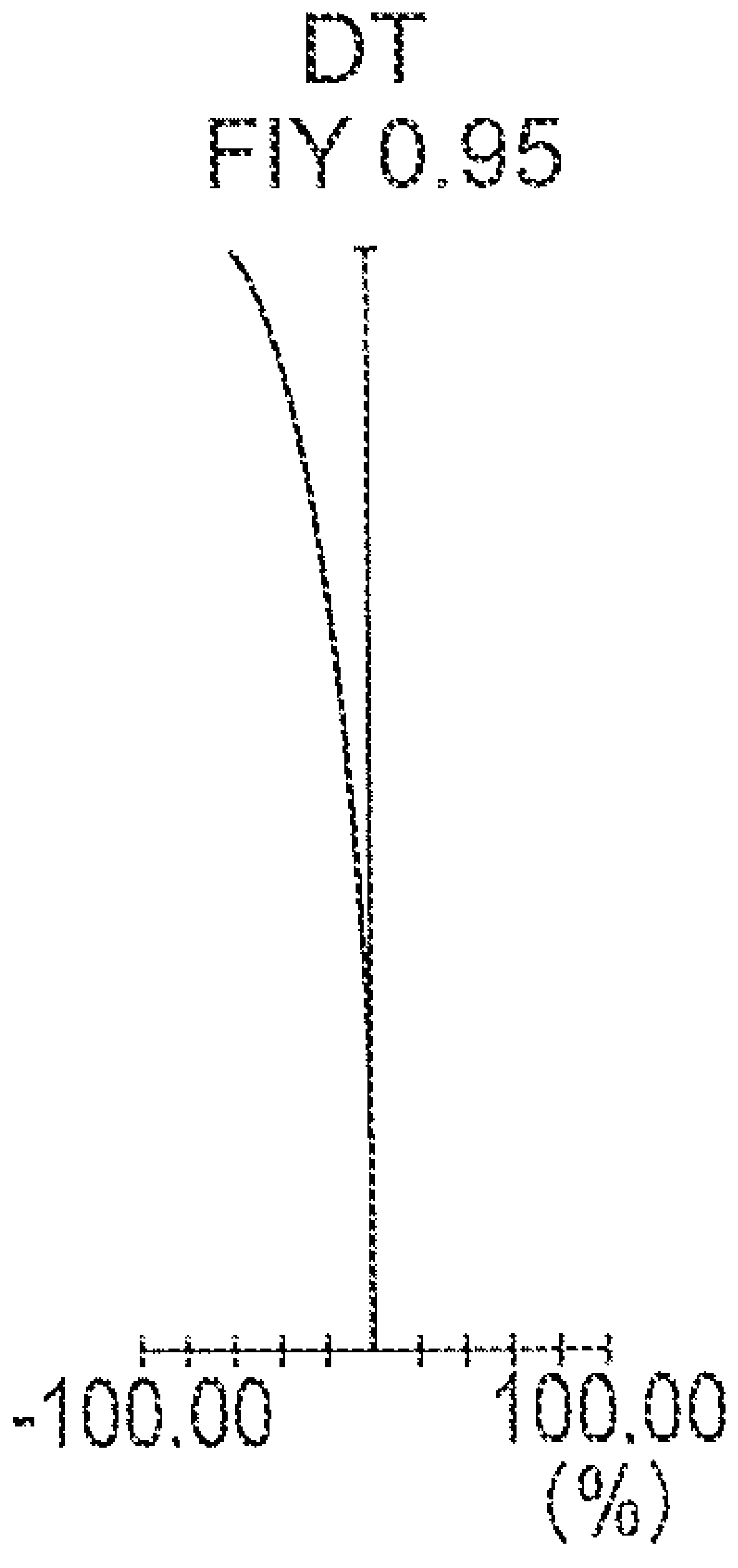


FIG. 25E

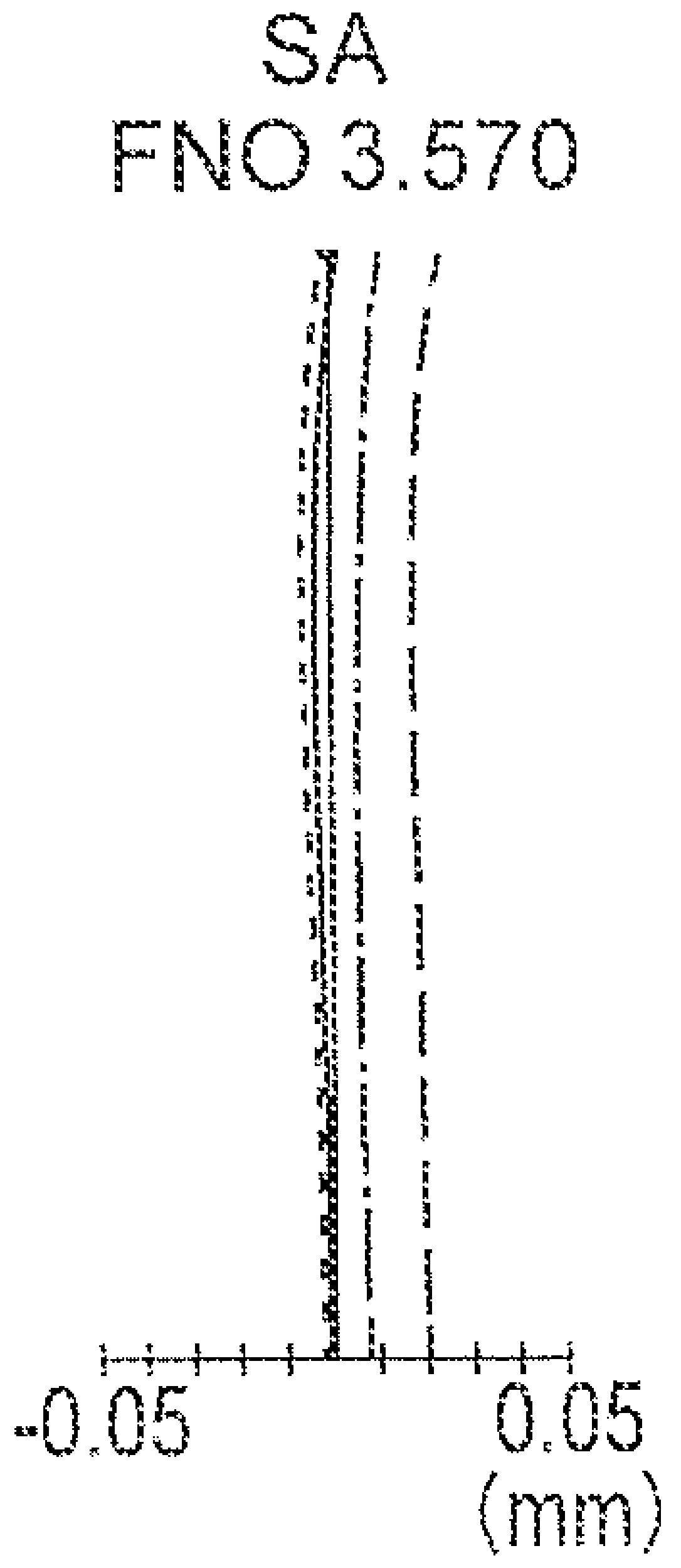


FIG. 25F

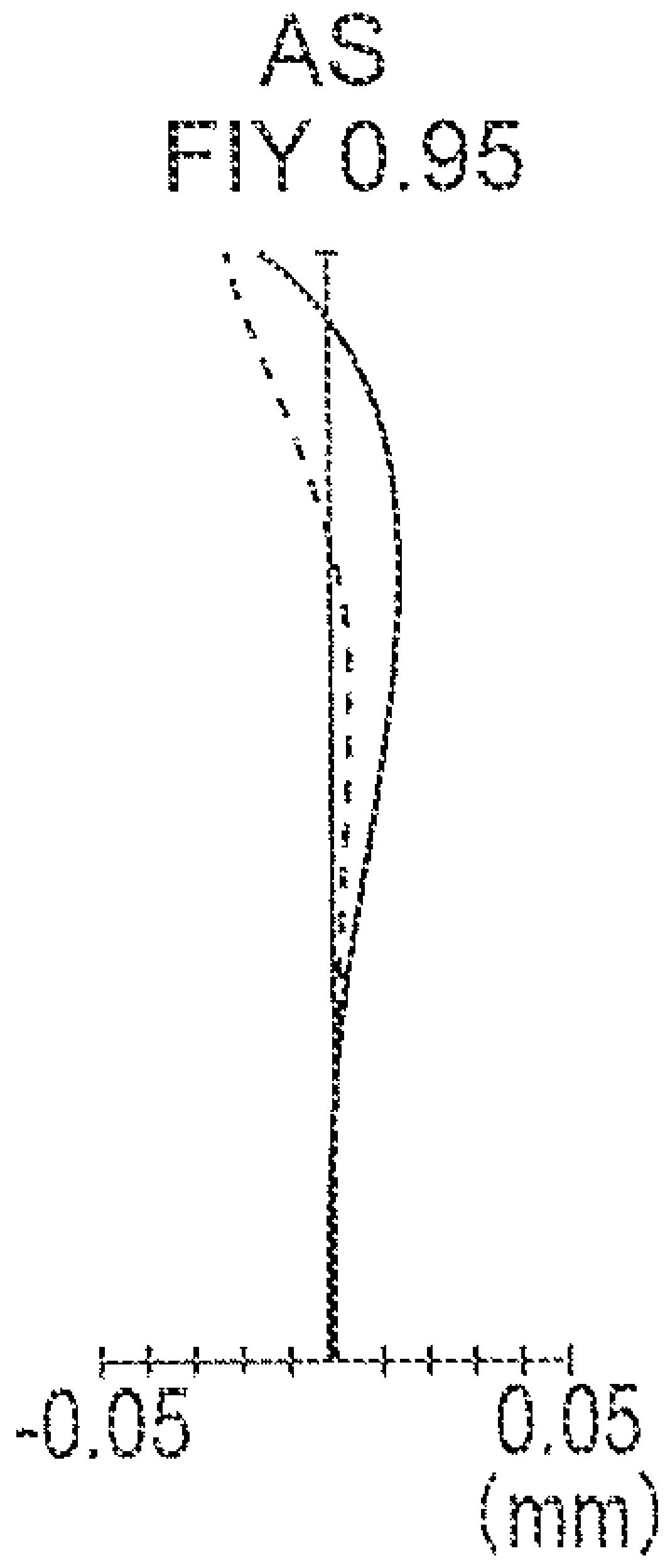


FIG. 25G

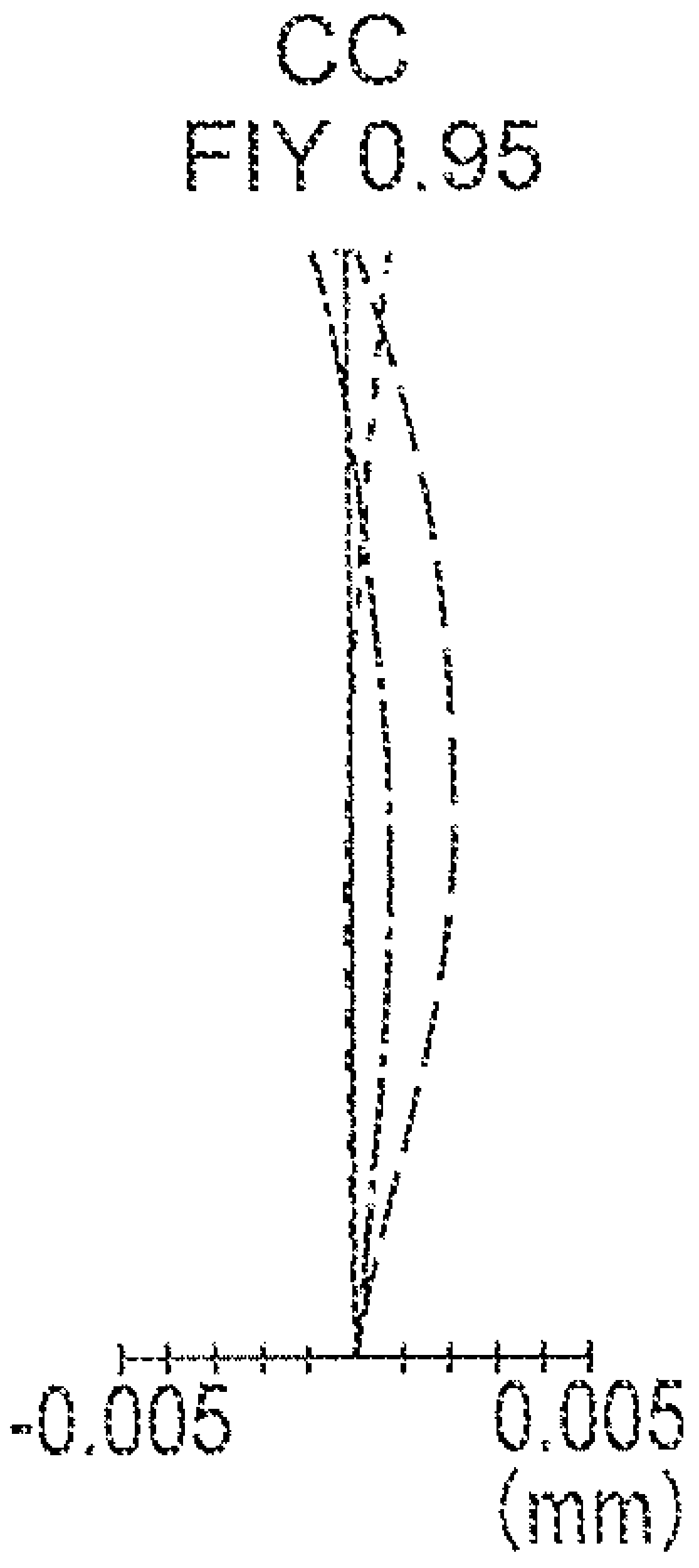


FIG. 25H

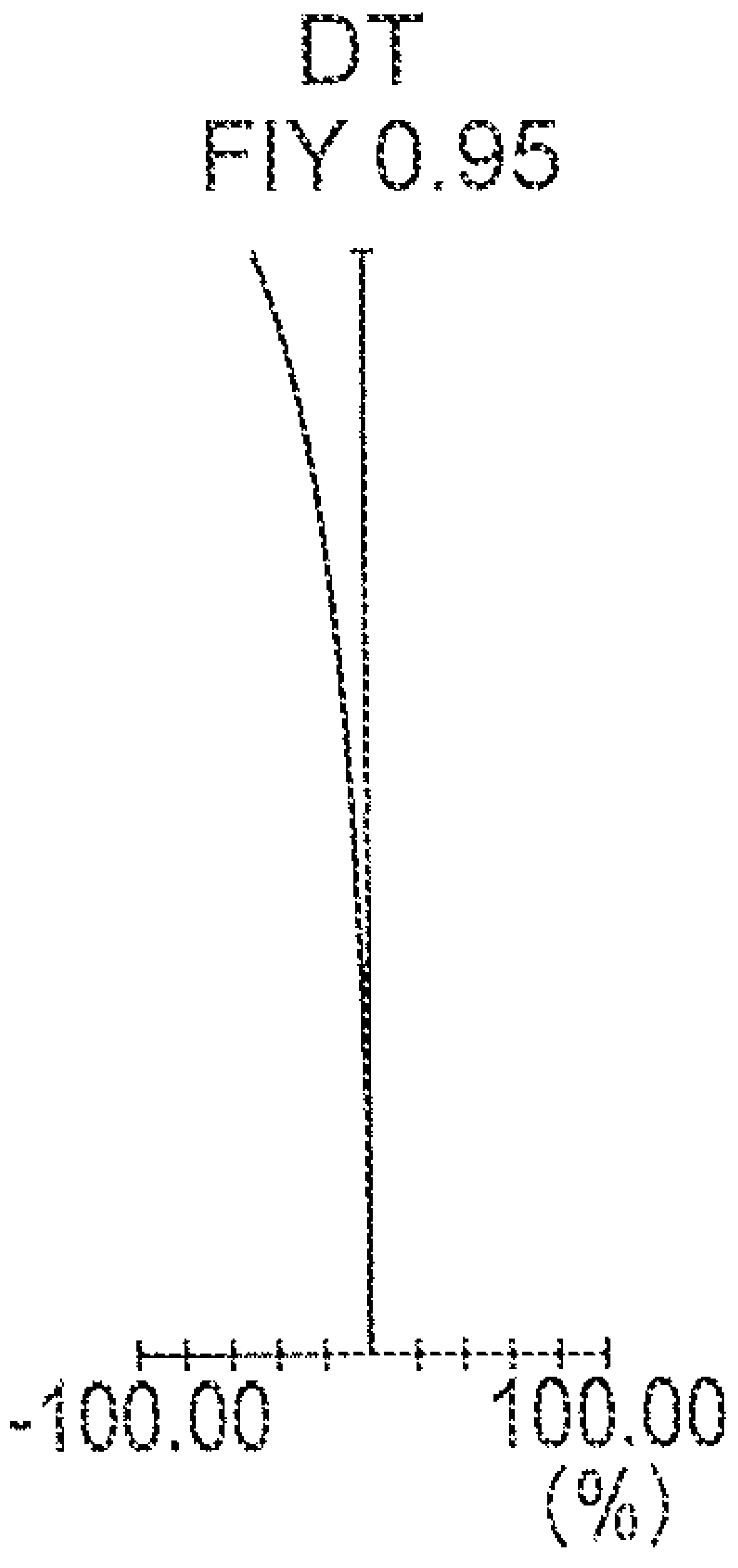


FIG. 26A

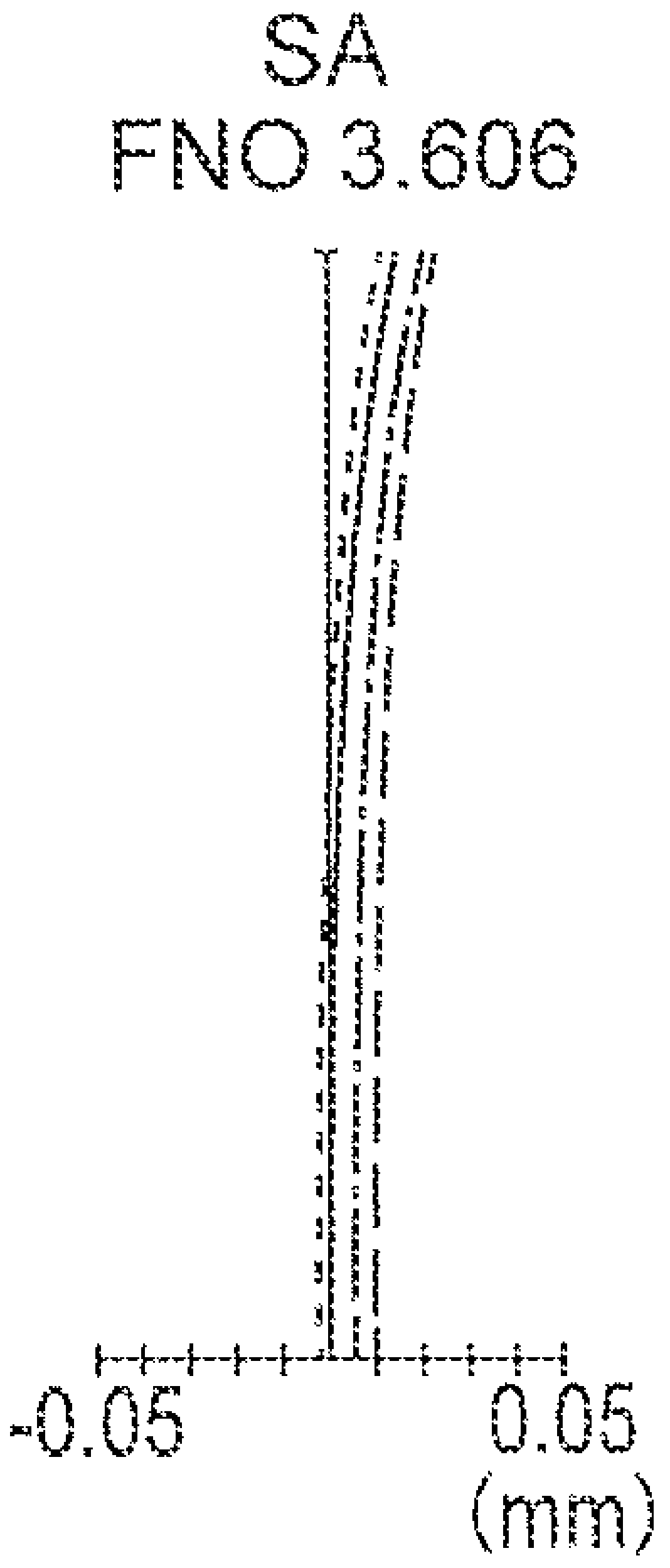


FIG. 26B

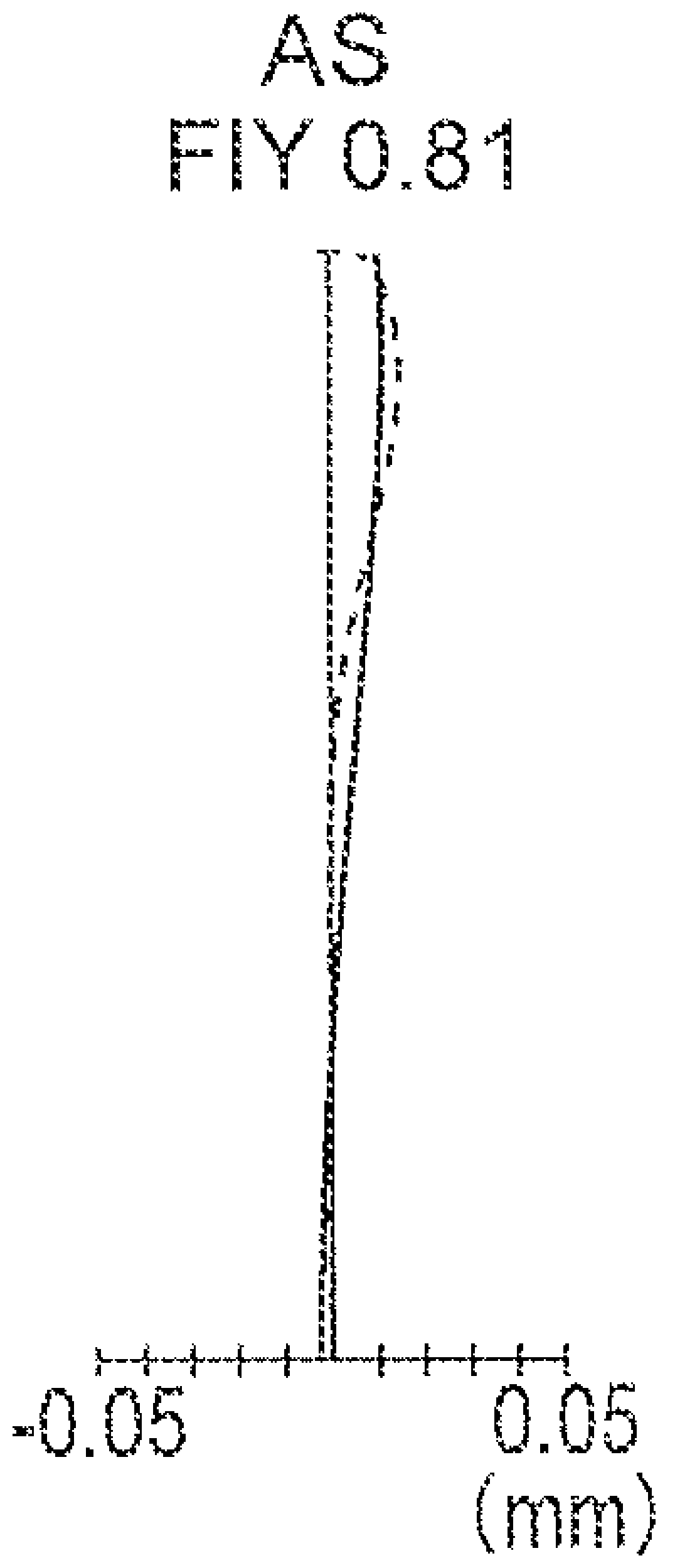


FIG. 26C

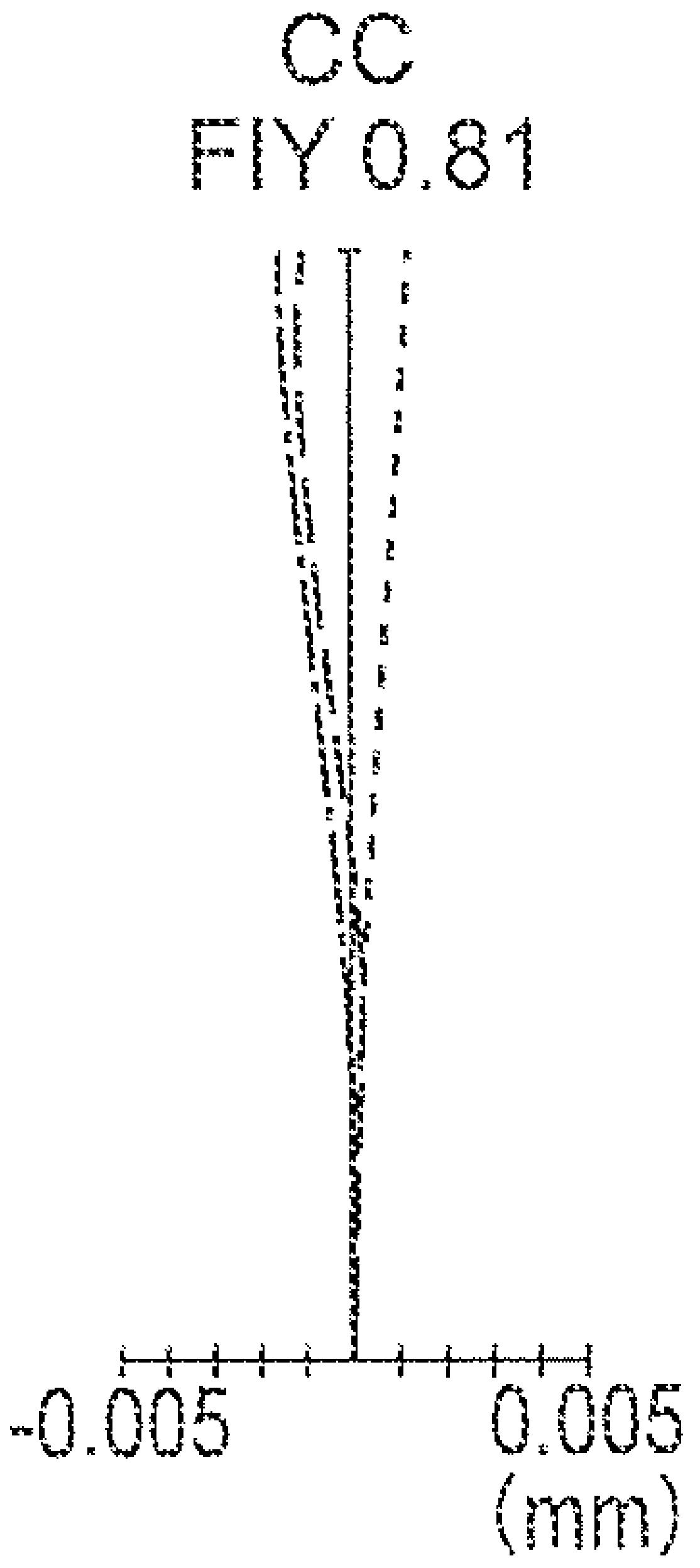


FIG. 26D

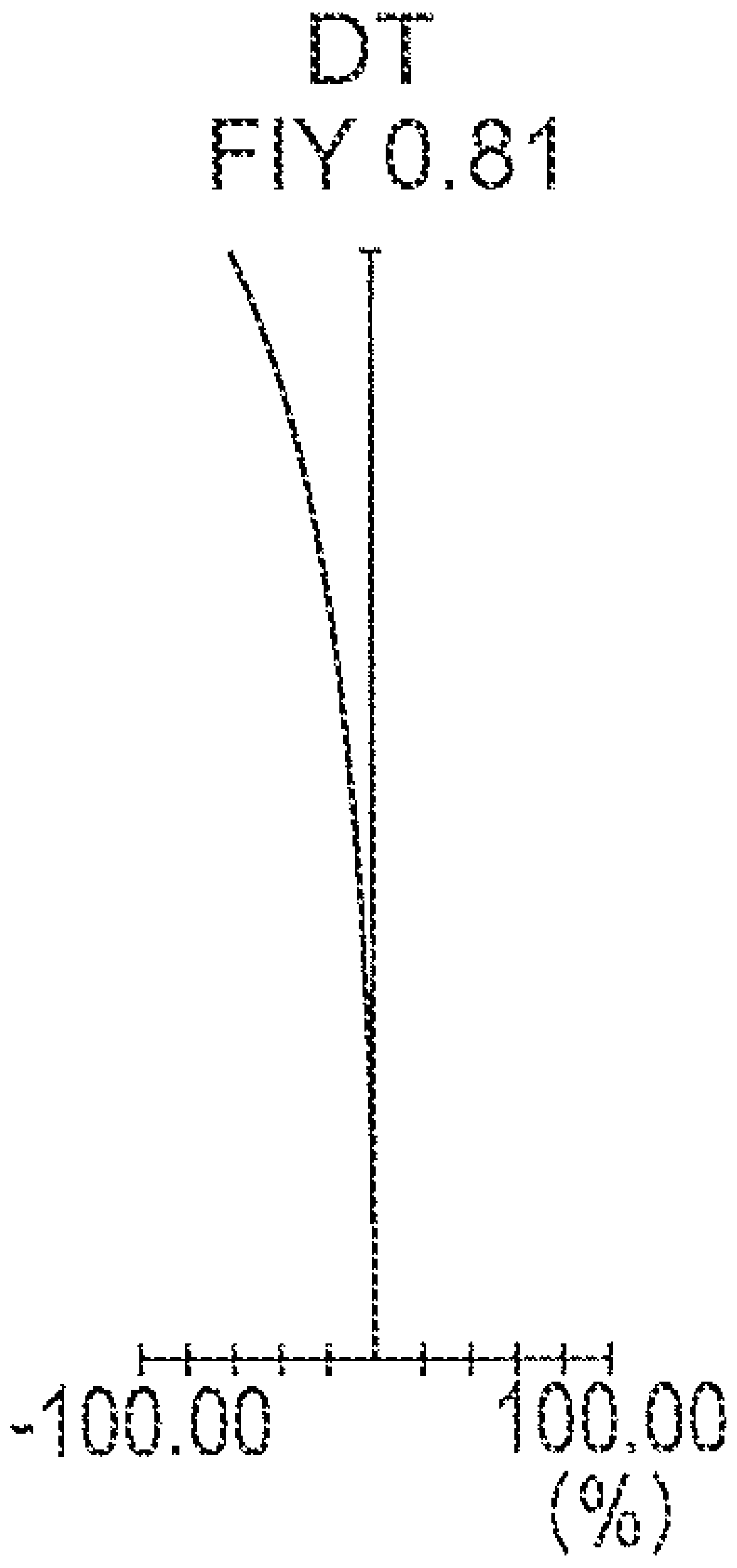


FIG. 26E

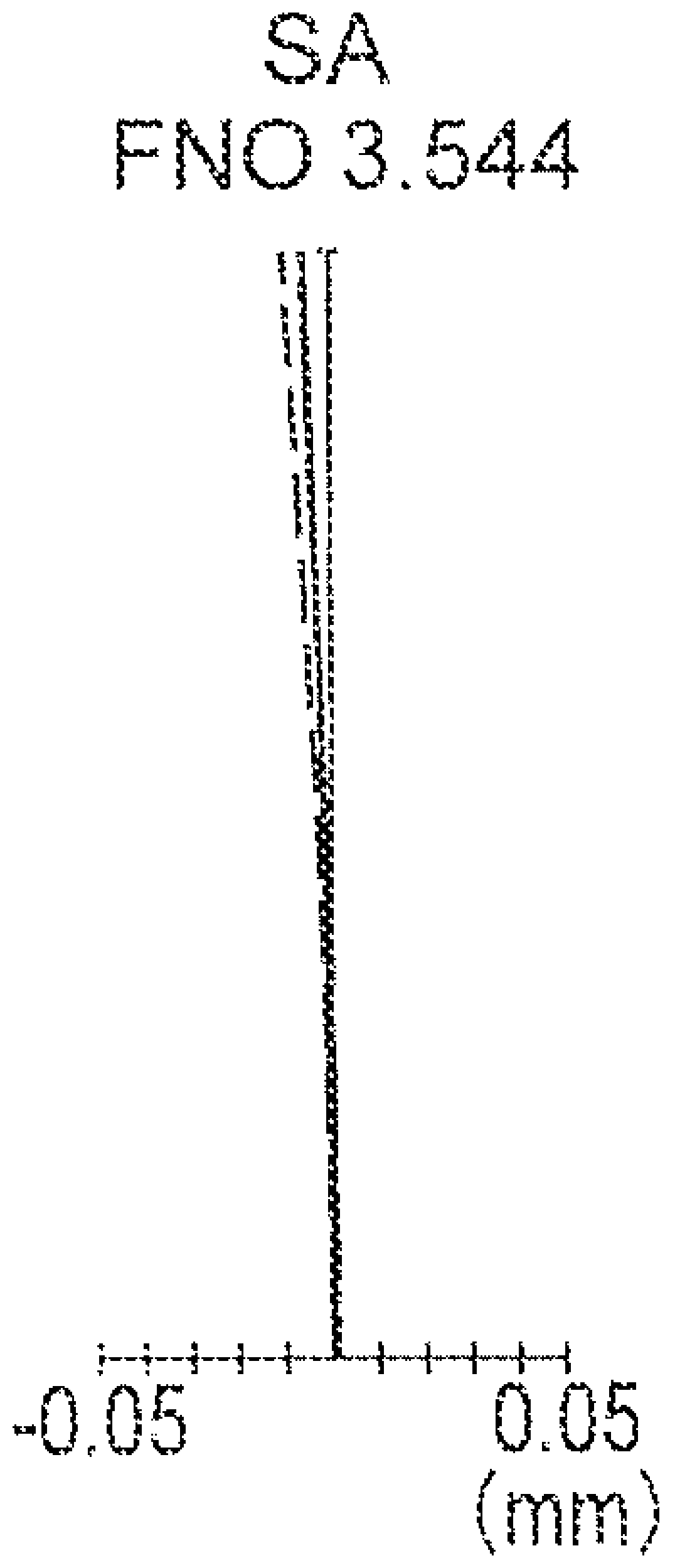


FIG. 26F

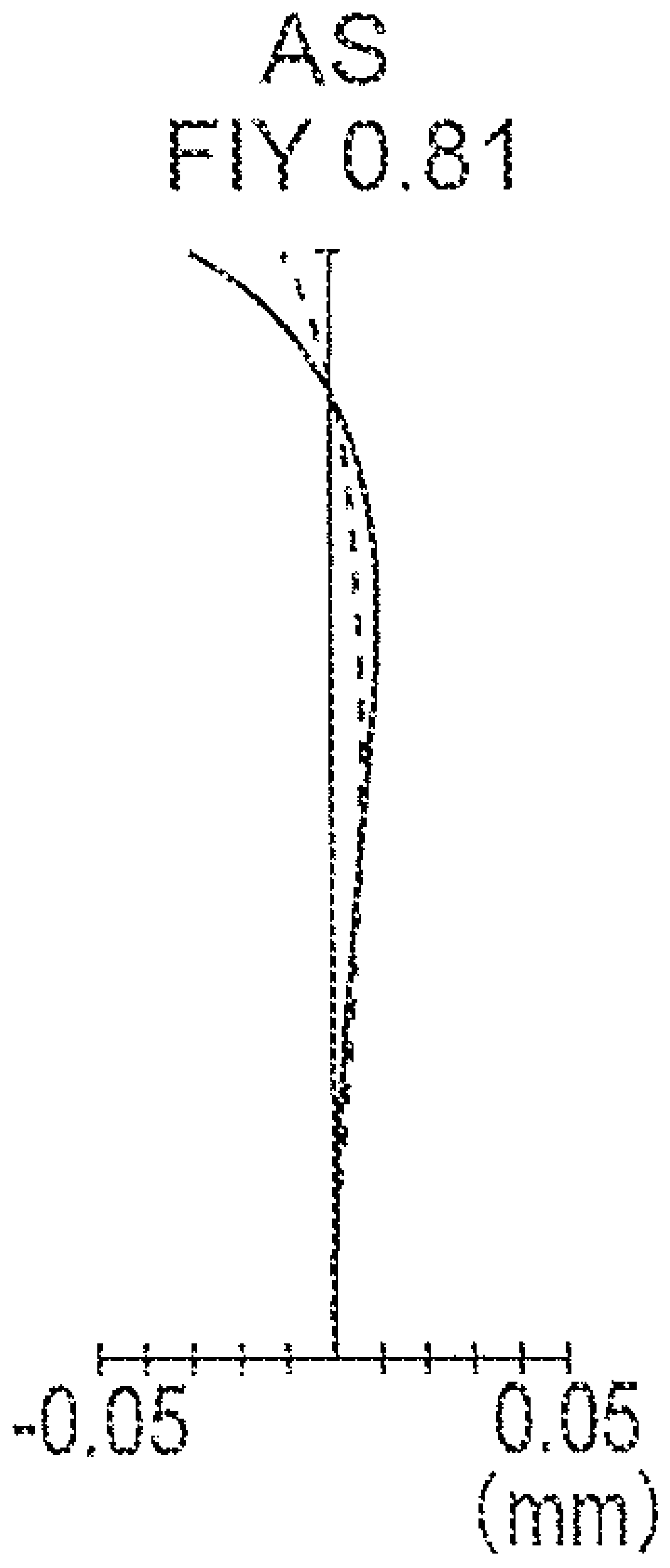


FIG. 26G

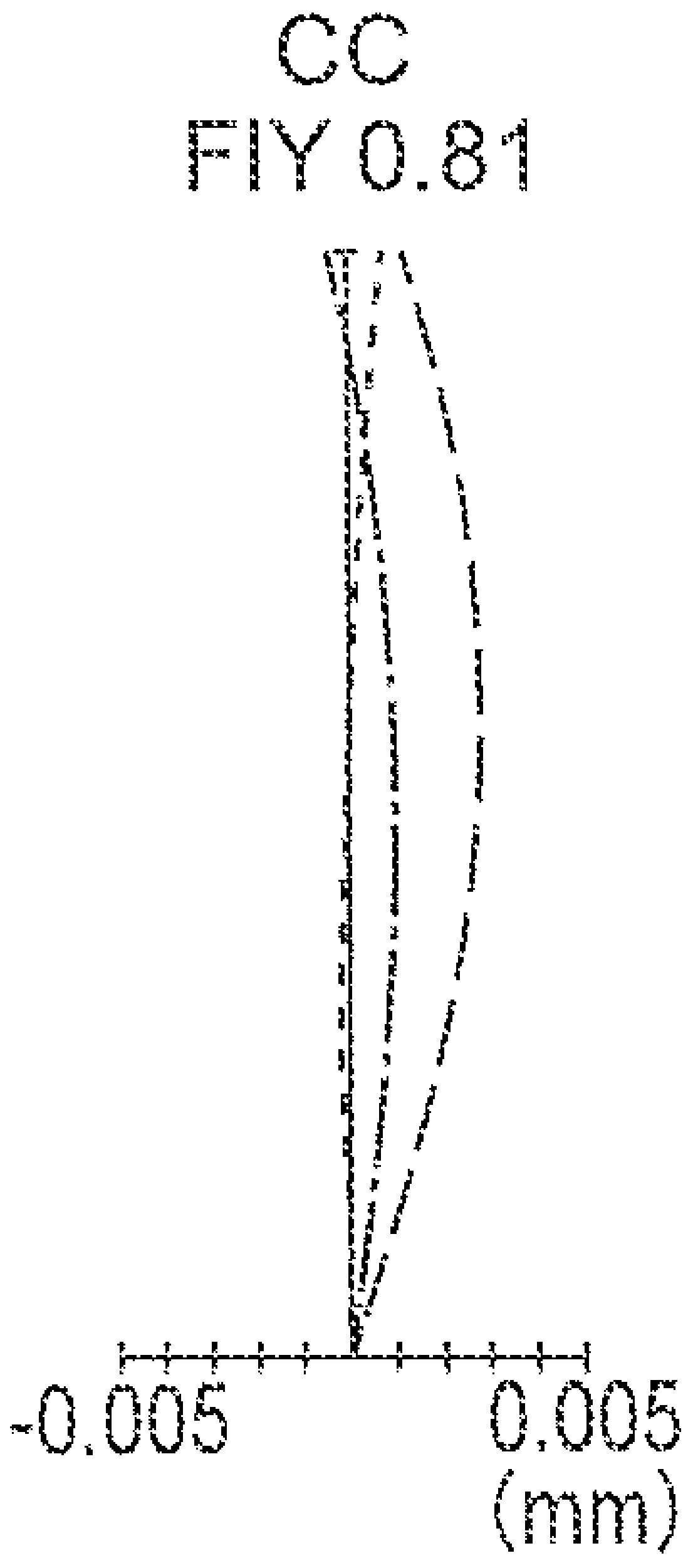


FIG. 26H

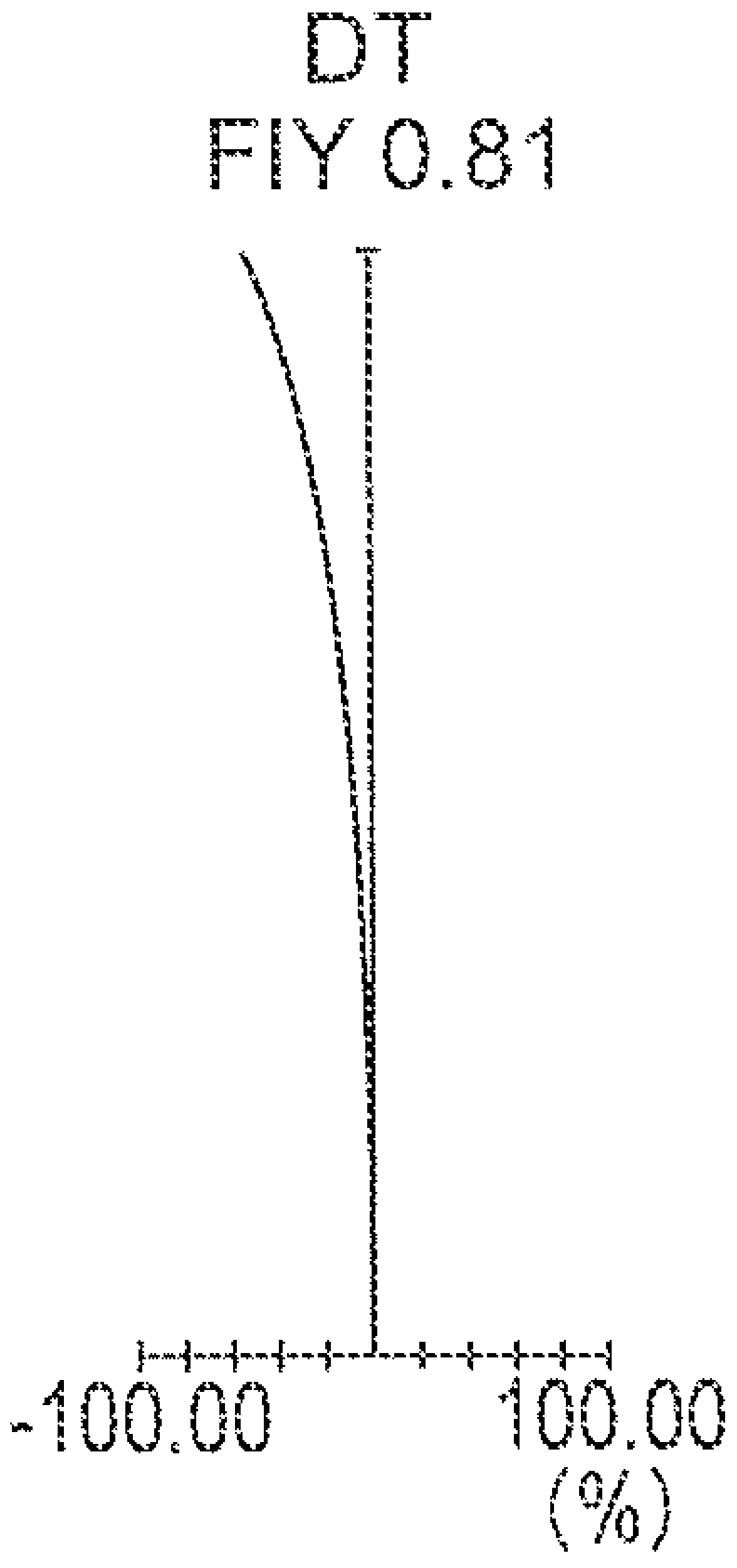


FIG. 27A

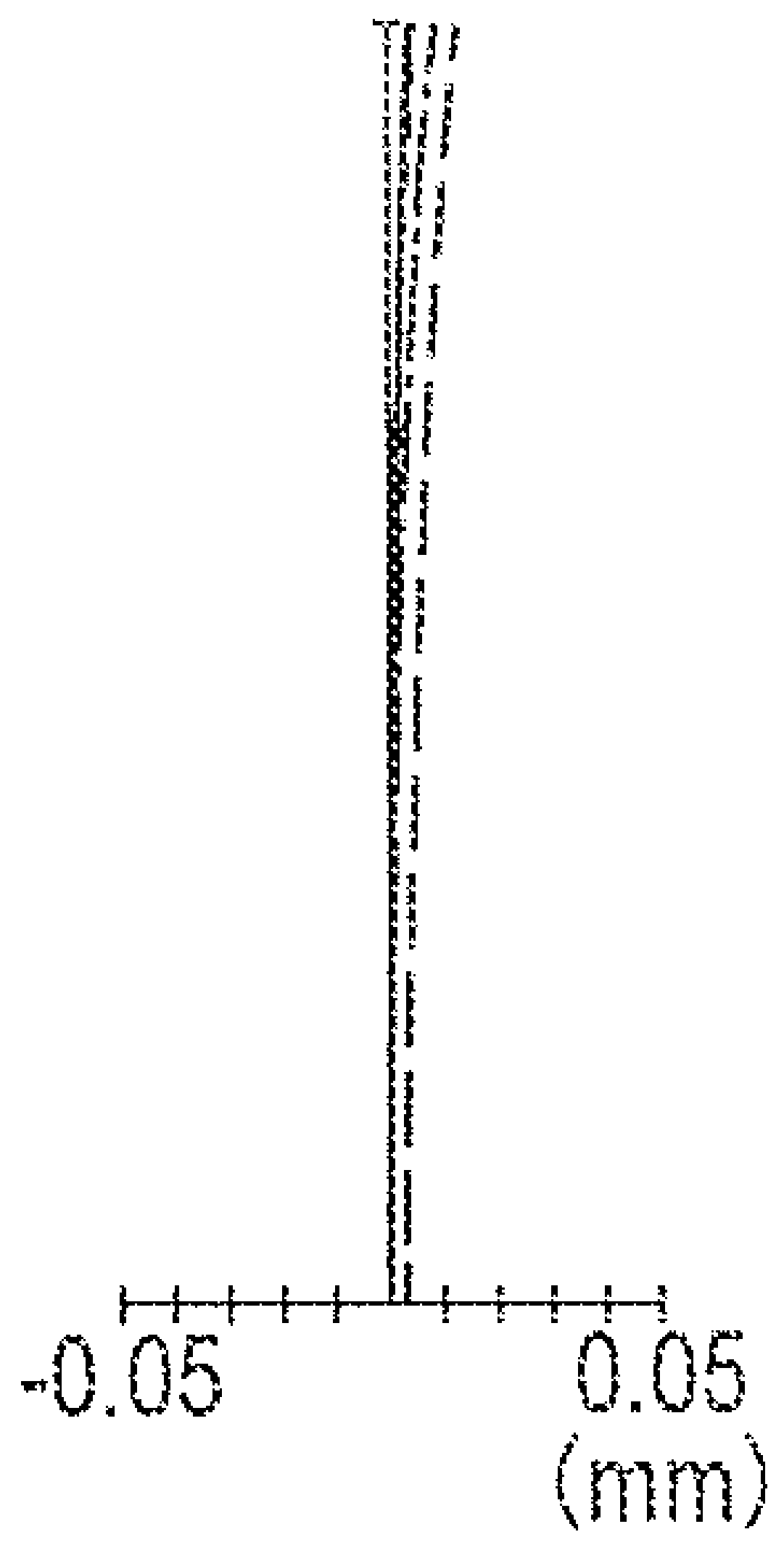

SA
FNO 3.764

FIG. 27B

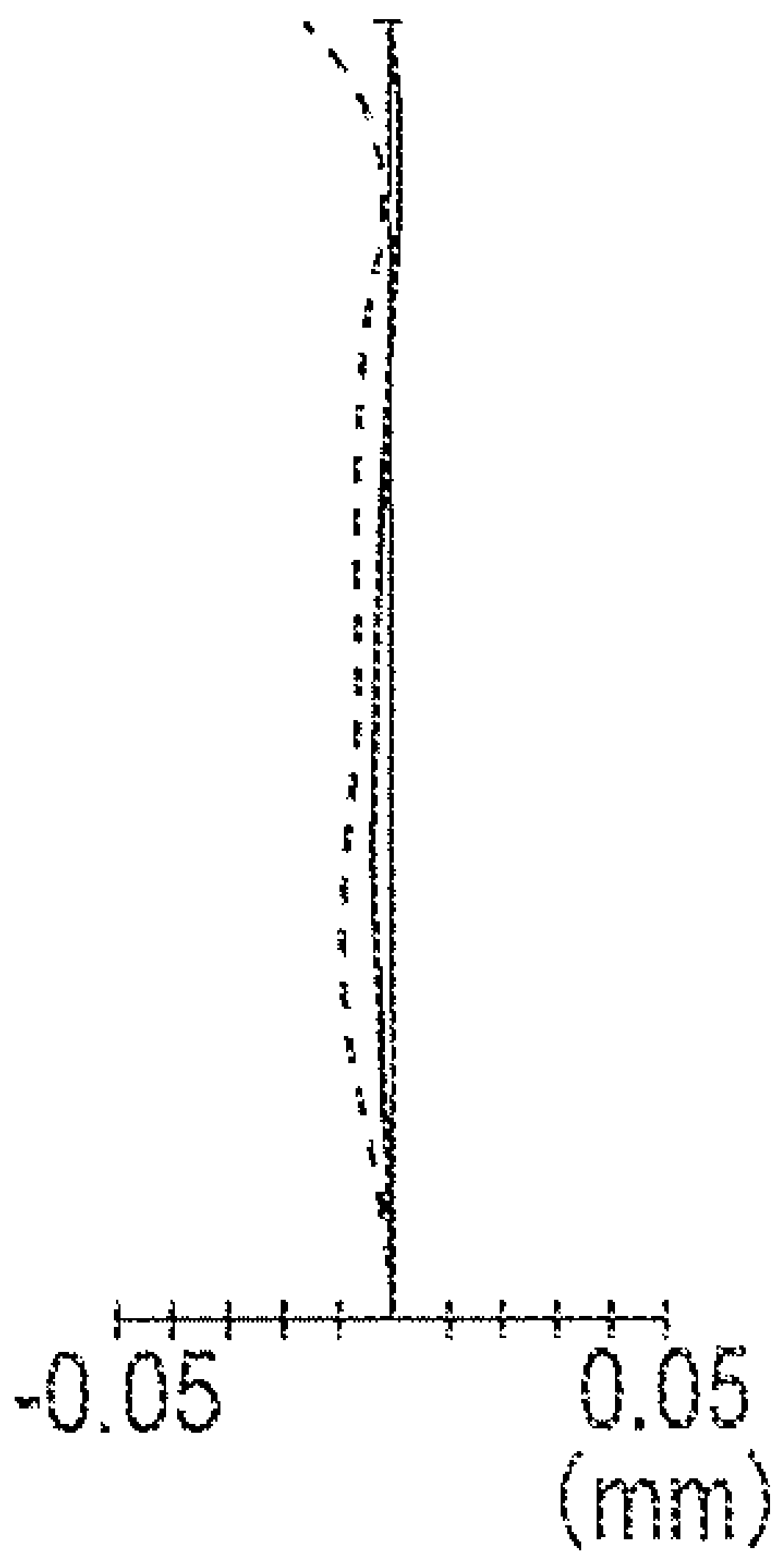

AS
FIY 0.64

FIG. 27C

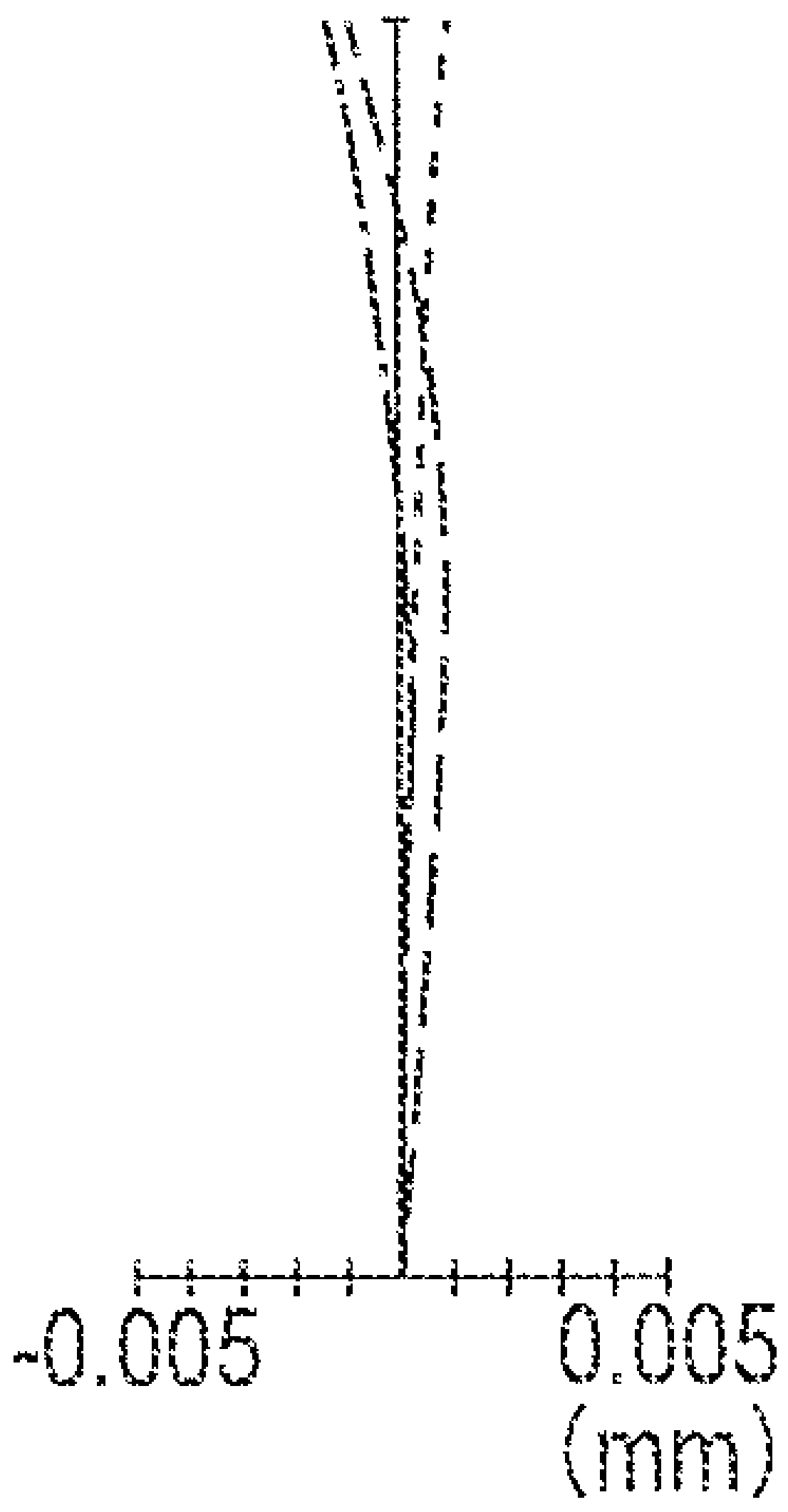

CC
FIY 0.64

FIG. 27D

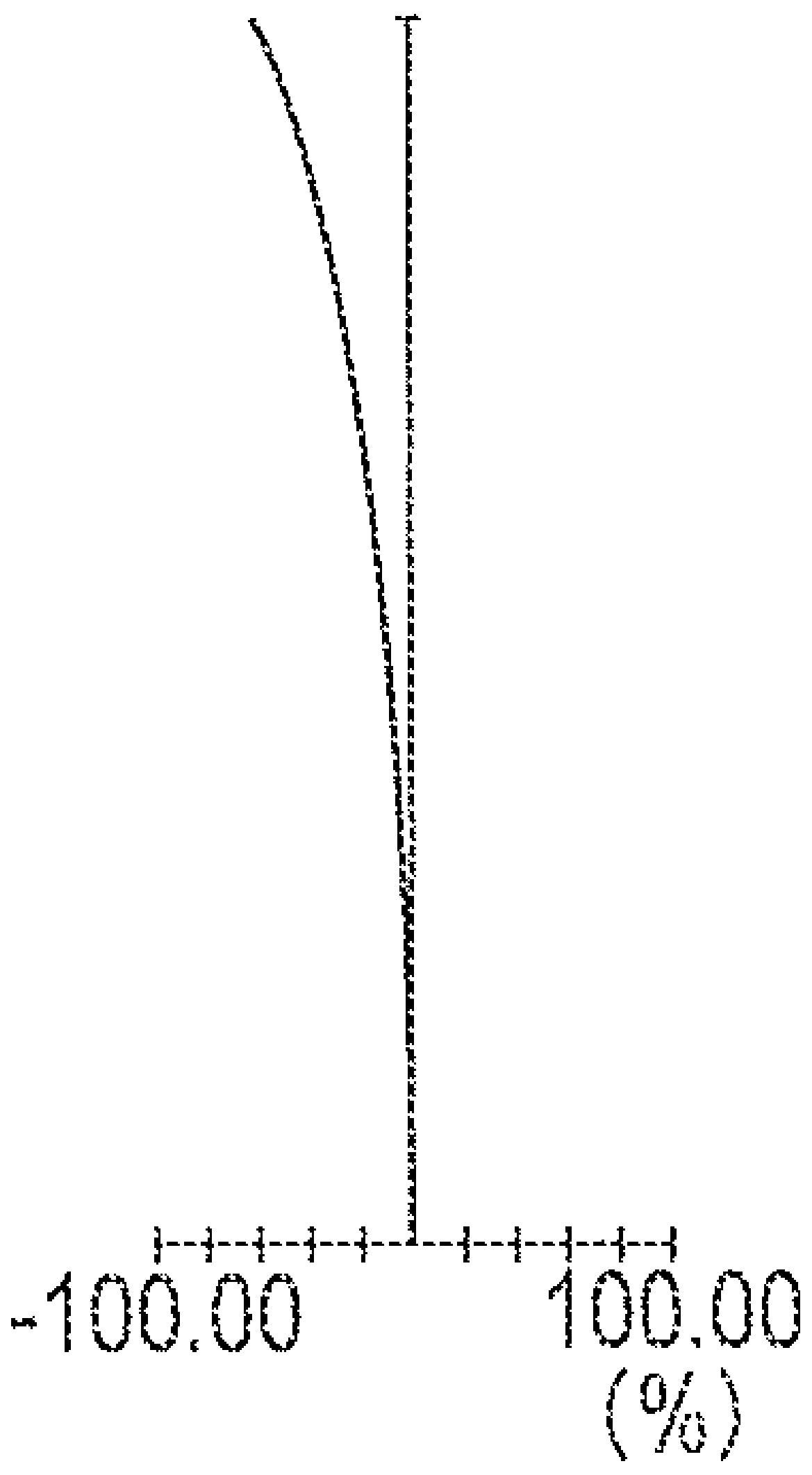

DT
FIY 0.64

FIG. 27E

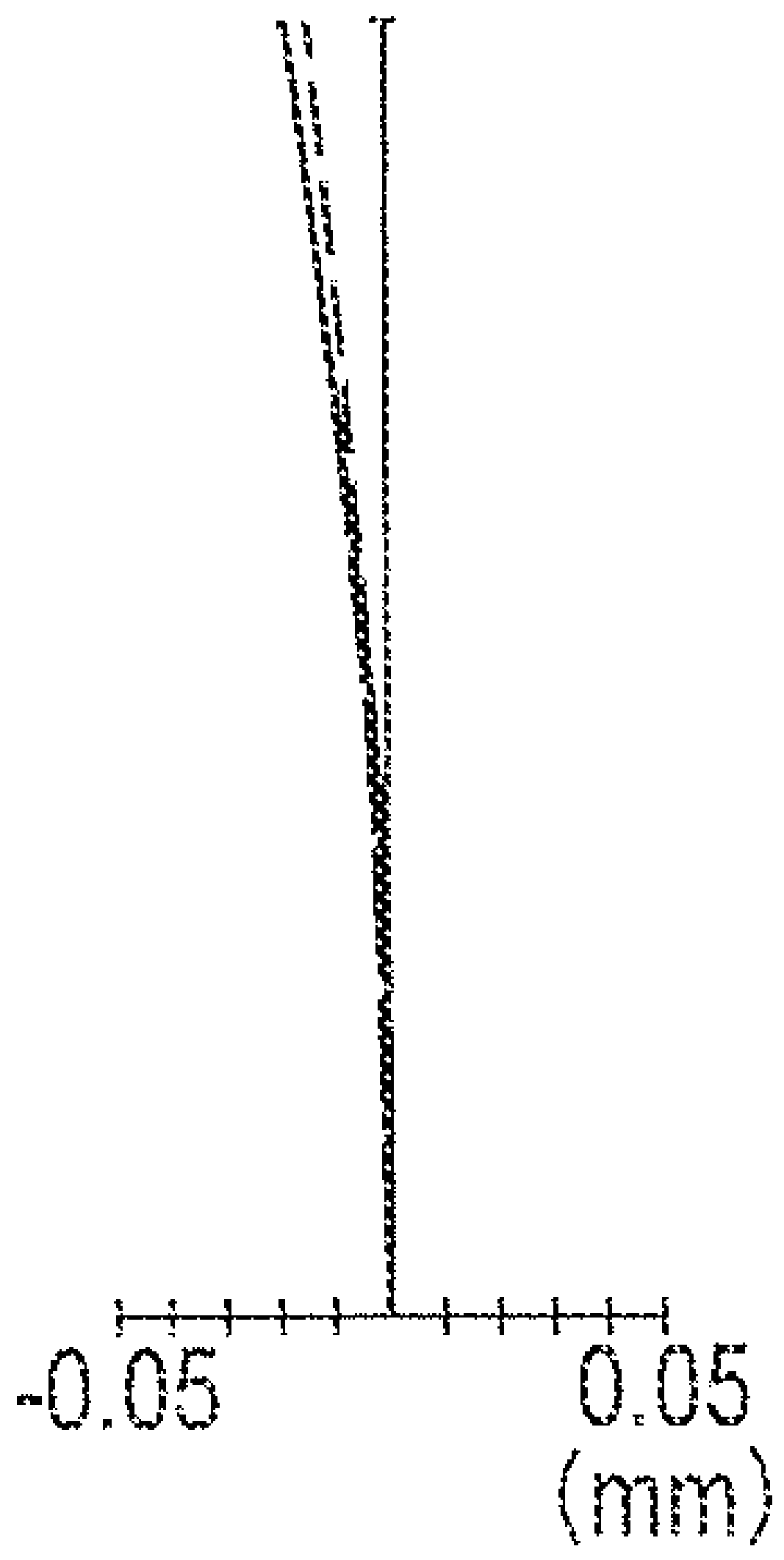

SA
FNO 3.822

FIG. 27F

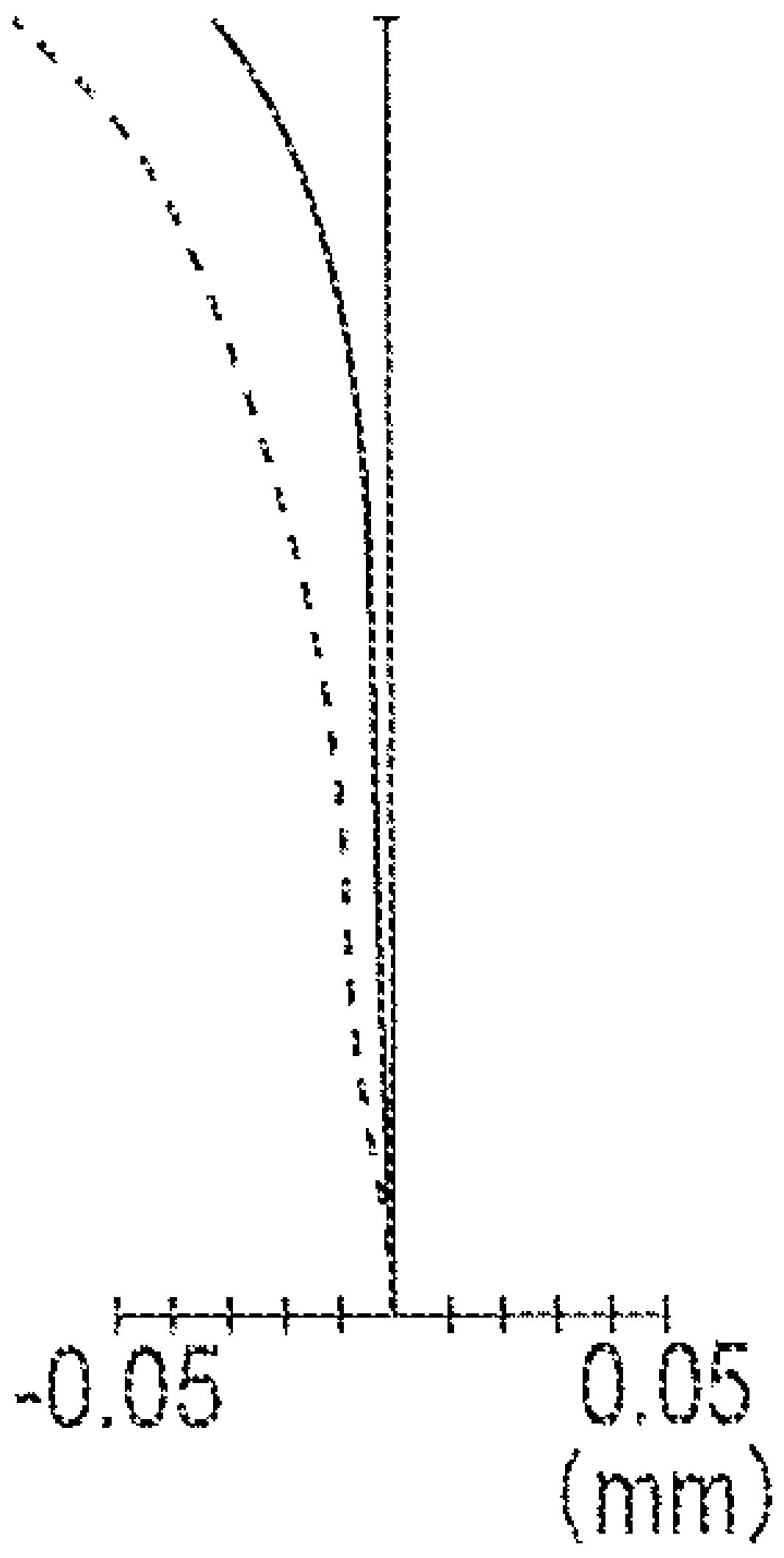

AS
FIY 0.64

FIG. 27G

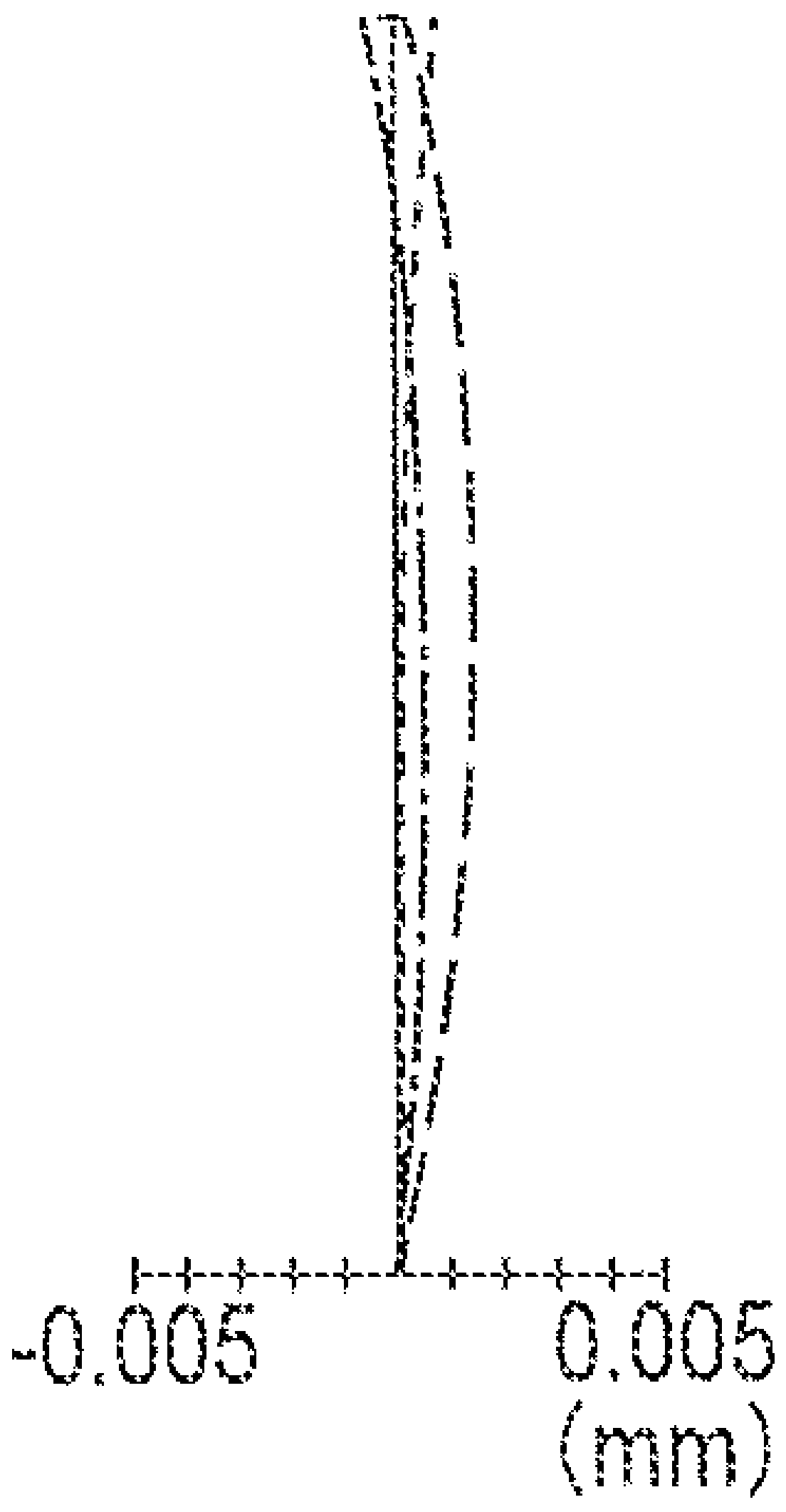

CC
FIY 0.64

FIG. 27H

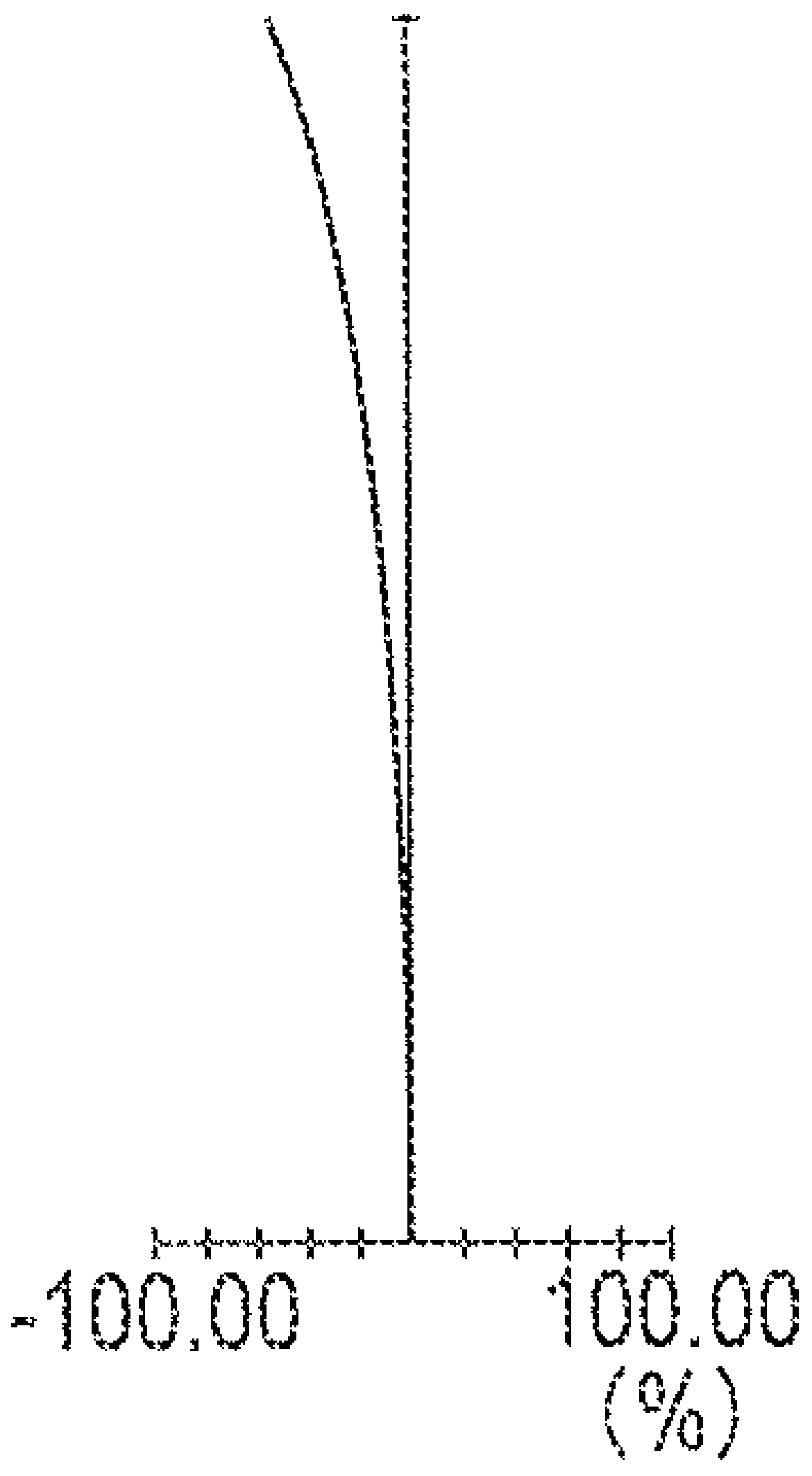

DT
FIY 0.64

FIG. 28A

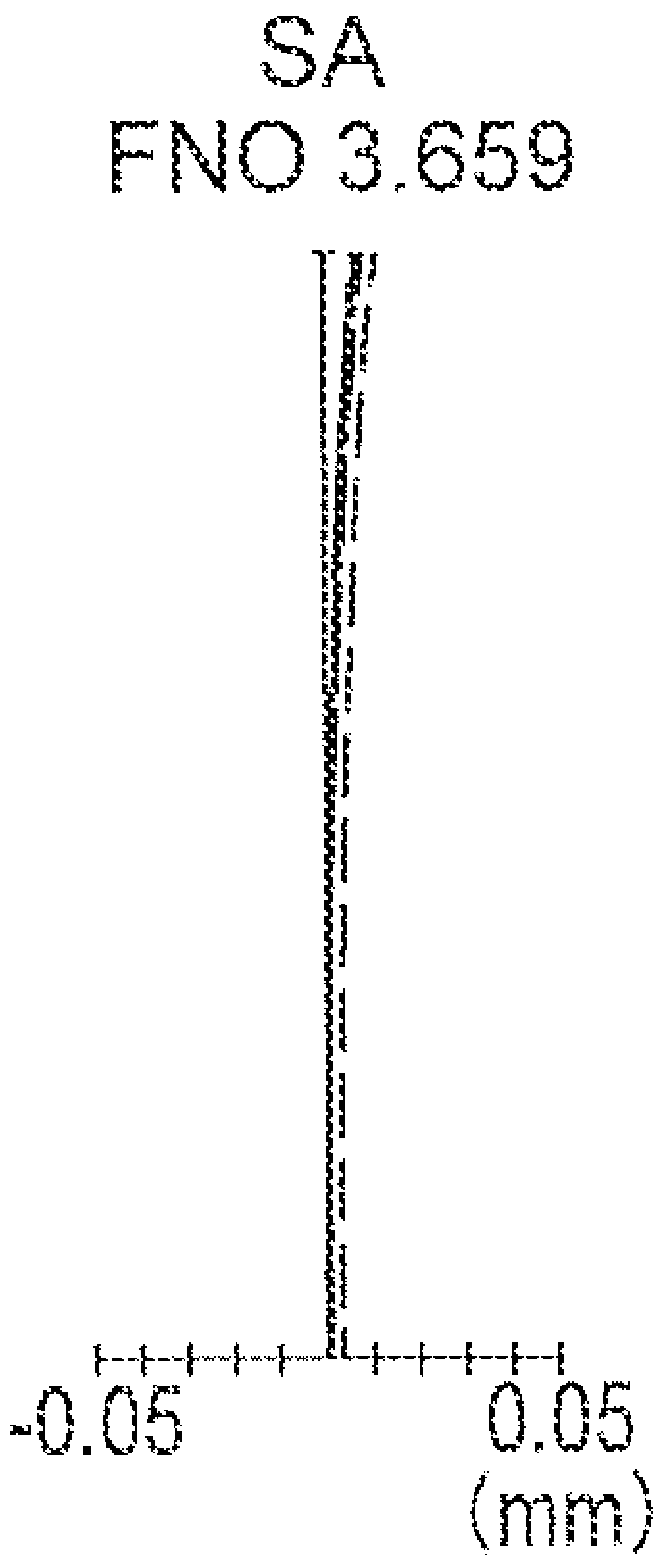


FIG. 28B

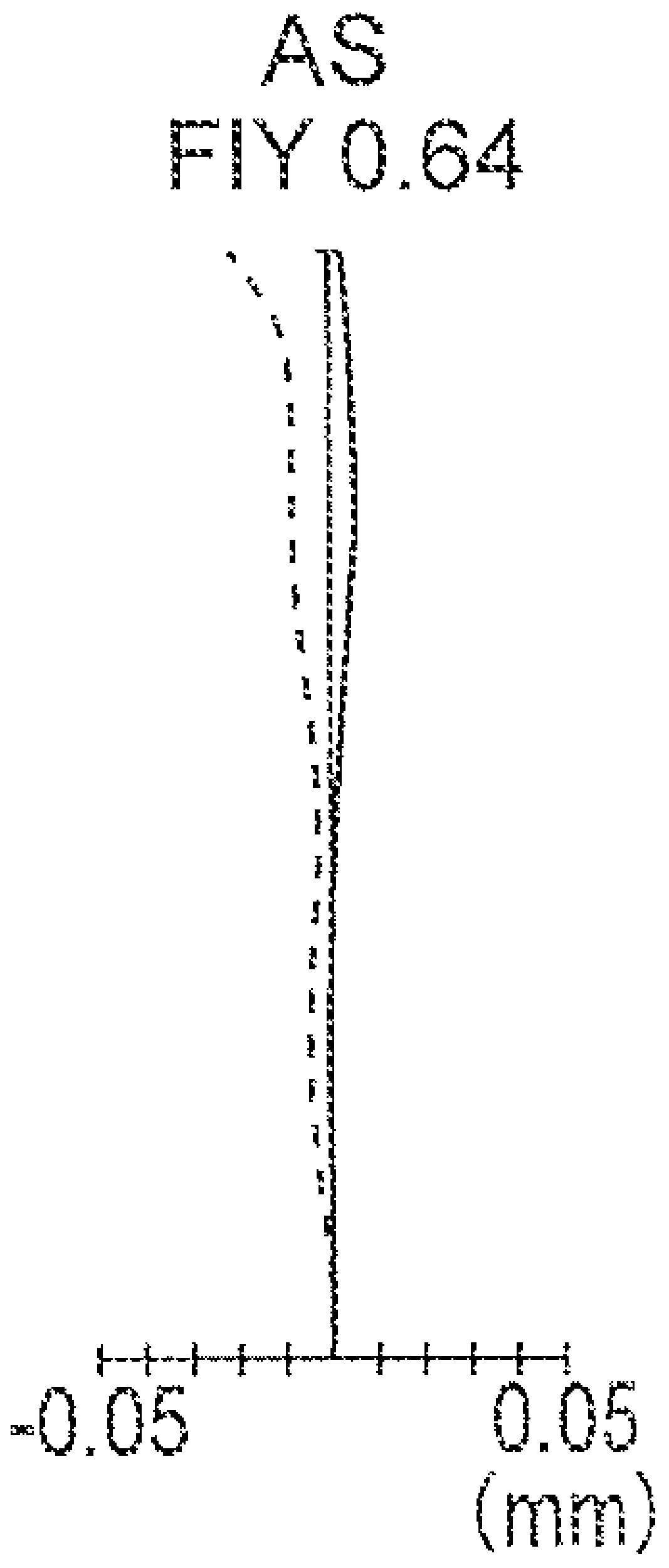


FIG. 28C

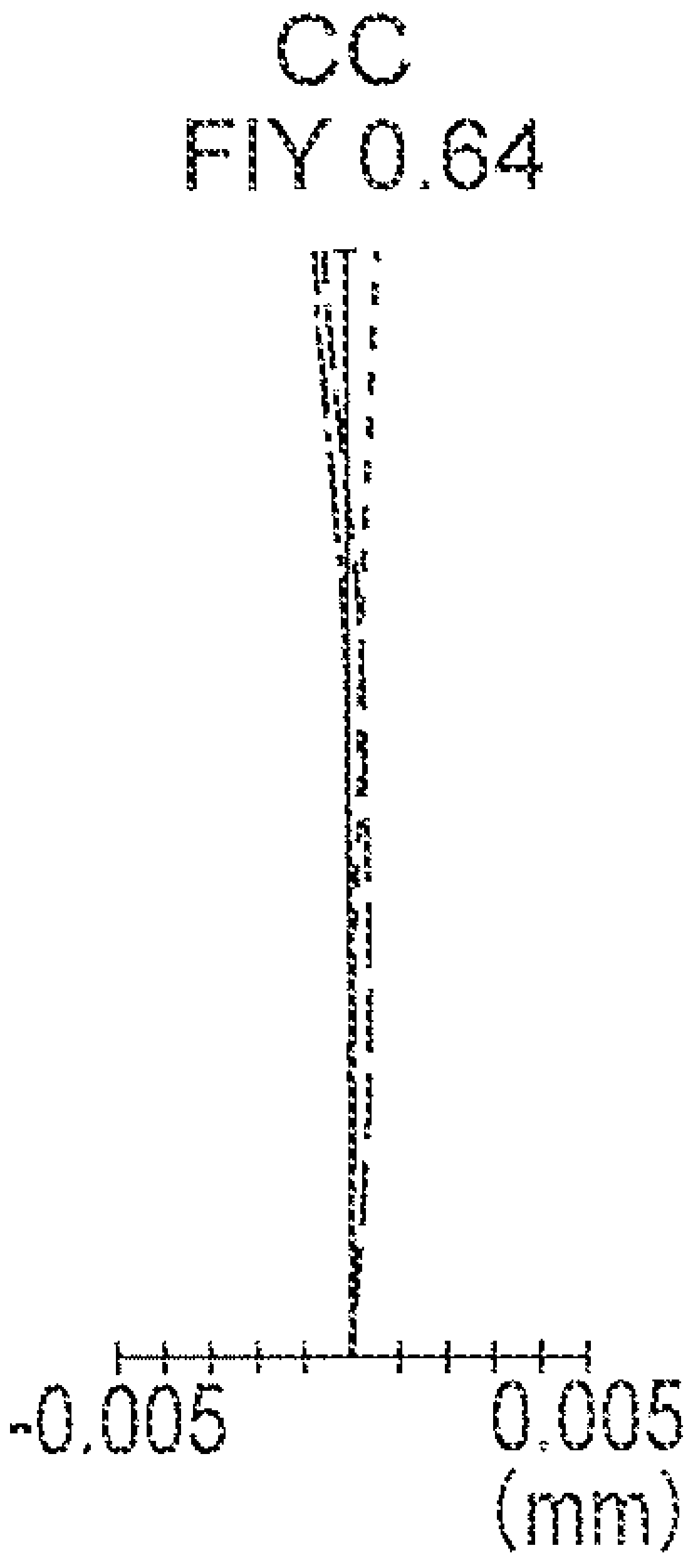


FIG. 28D

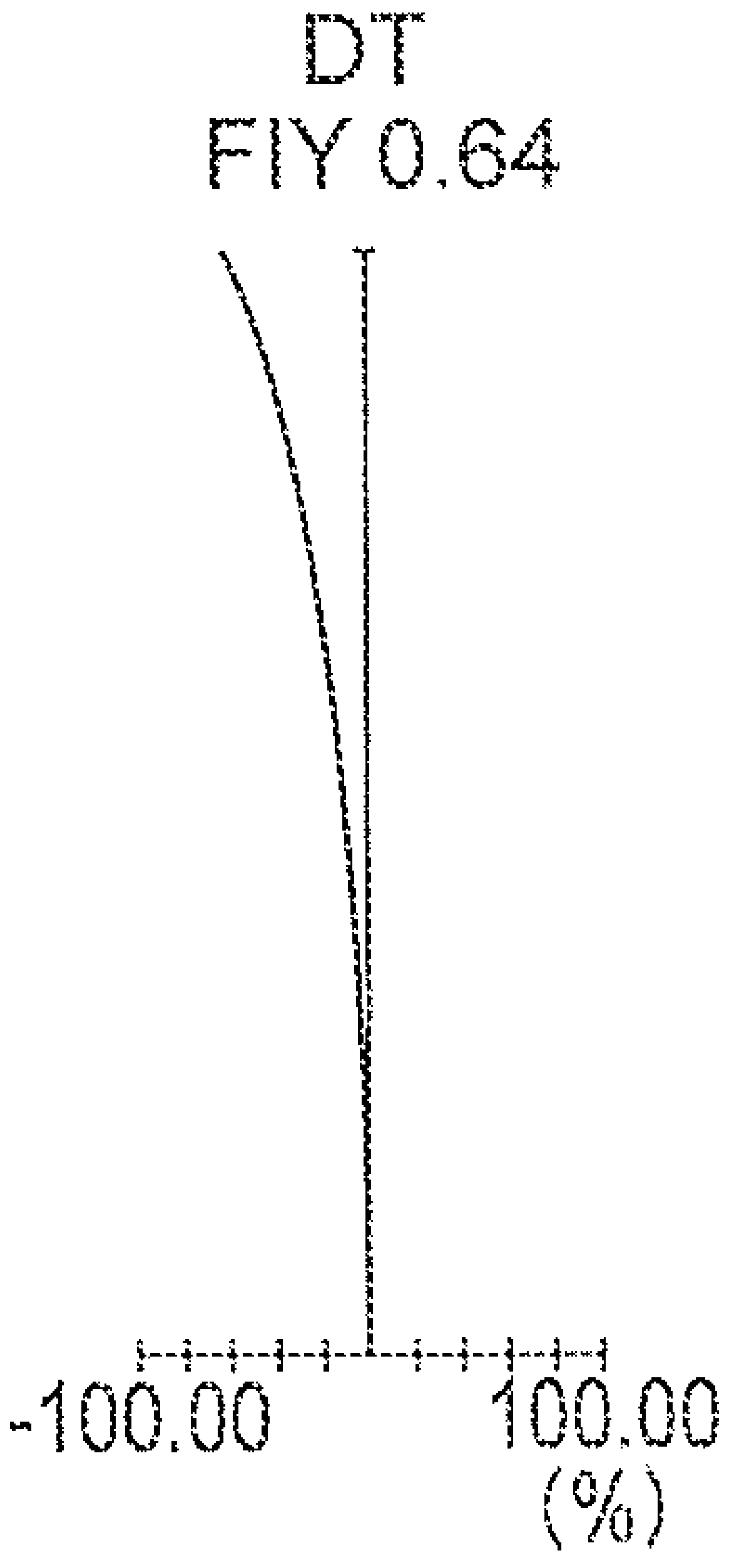


FIG. 28E

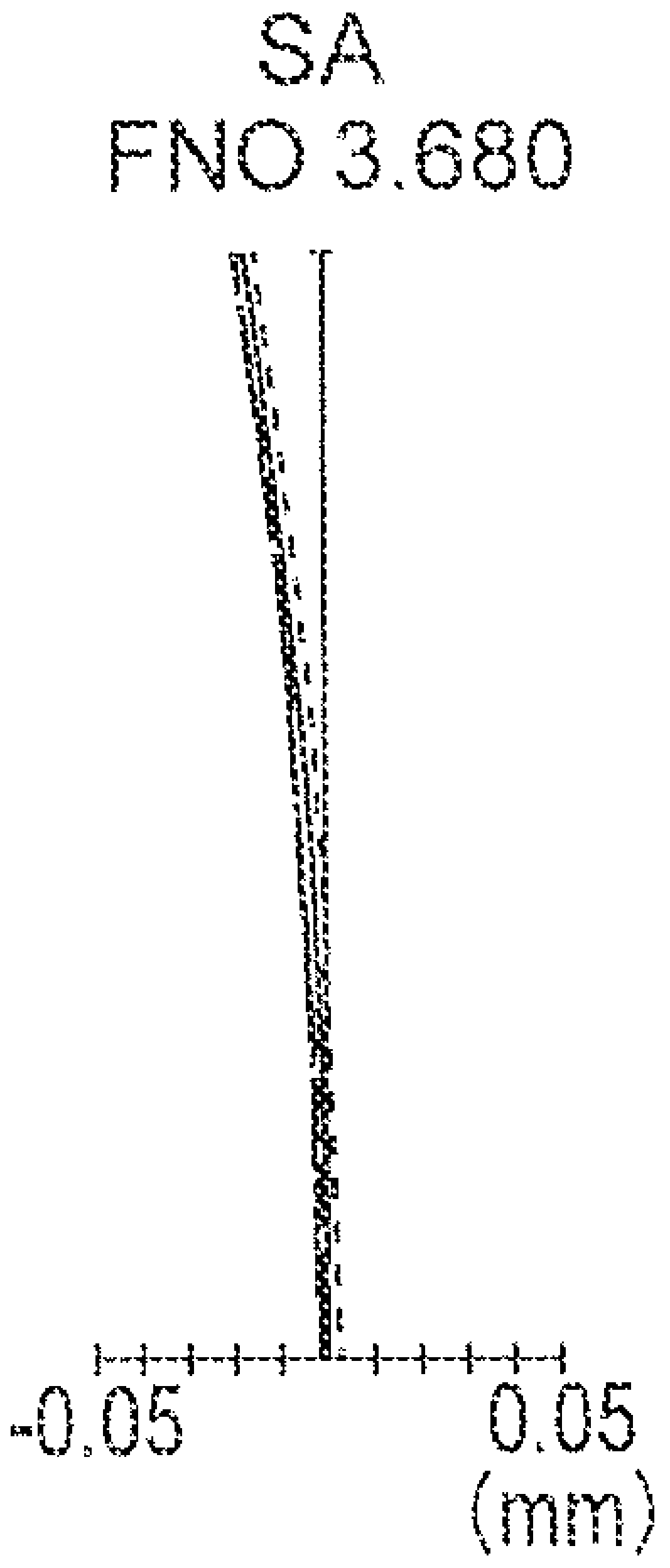


FIG. 28F

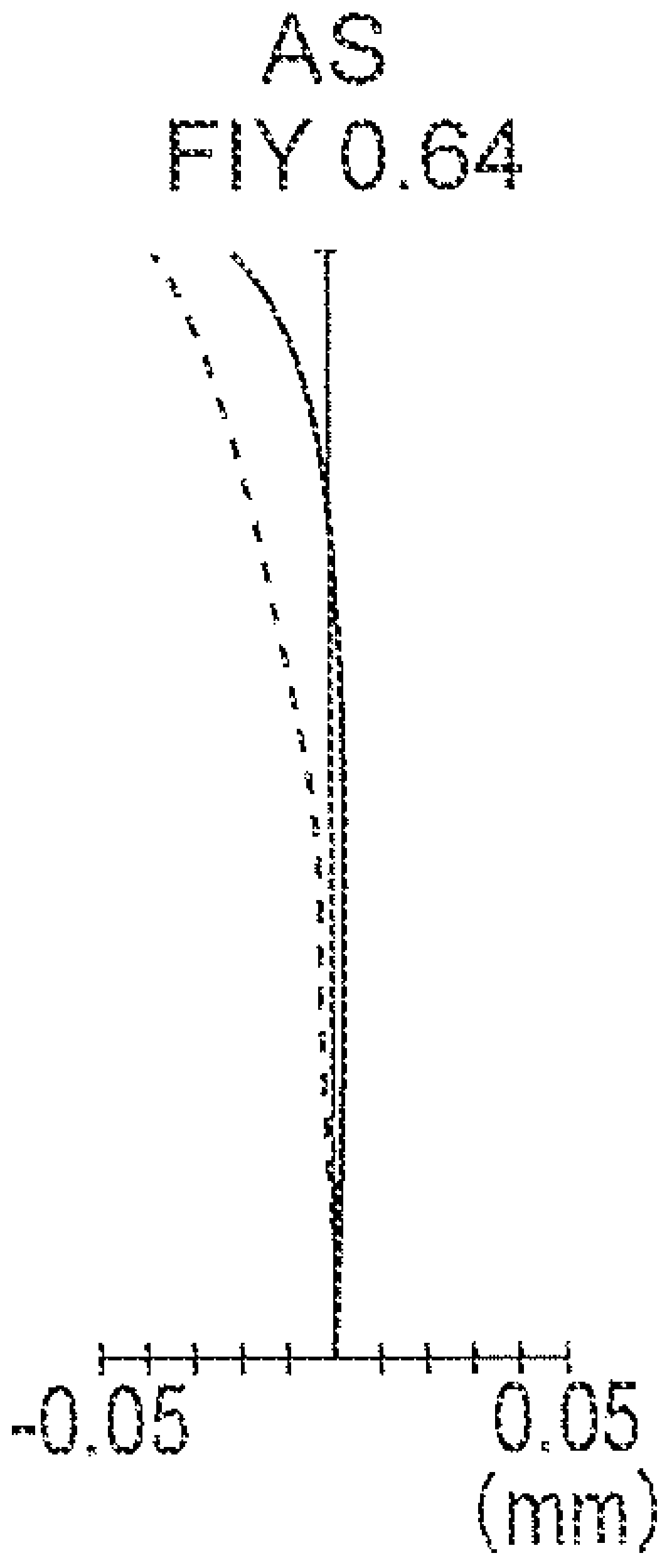


FIG. 28G

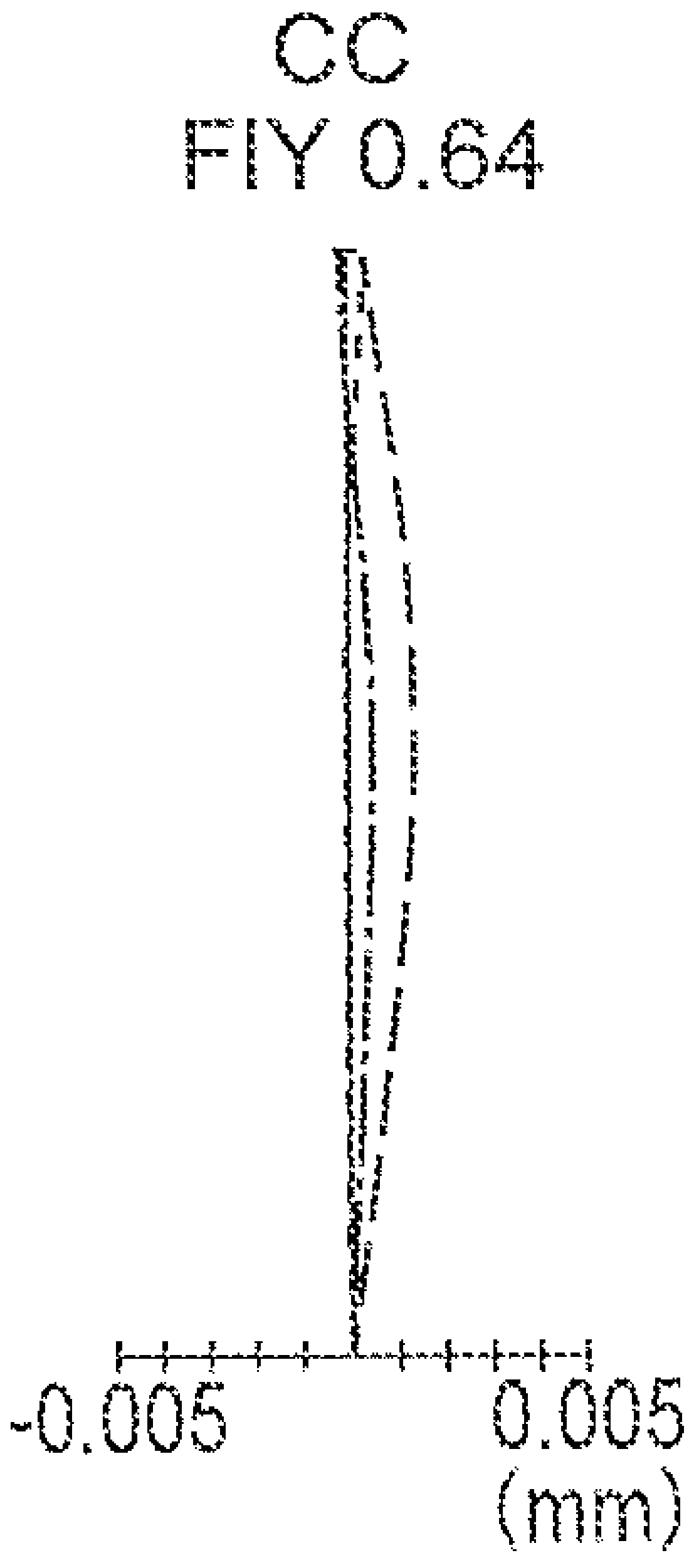


FIG. 28H

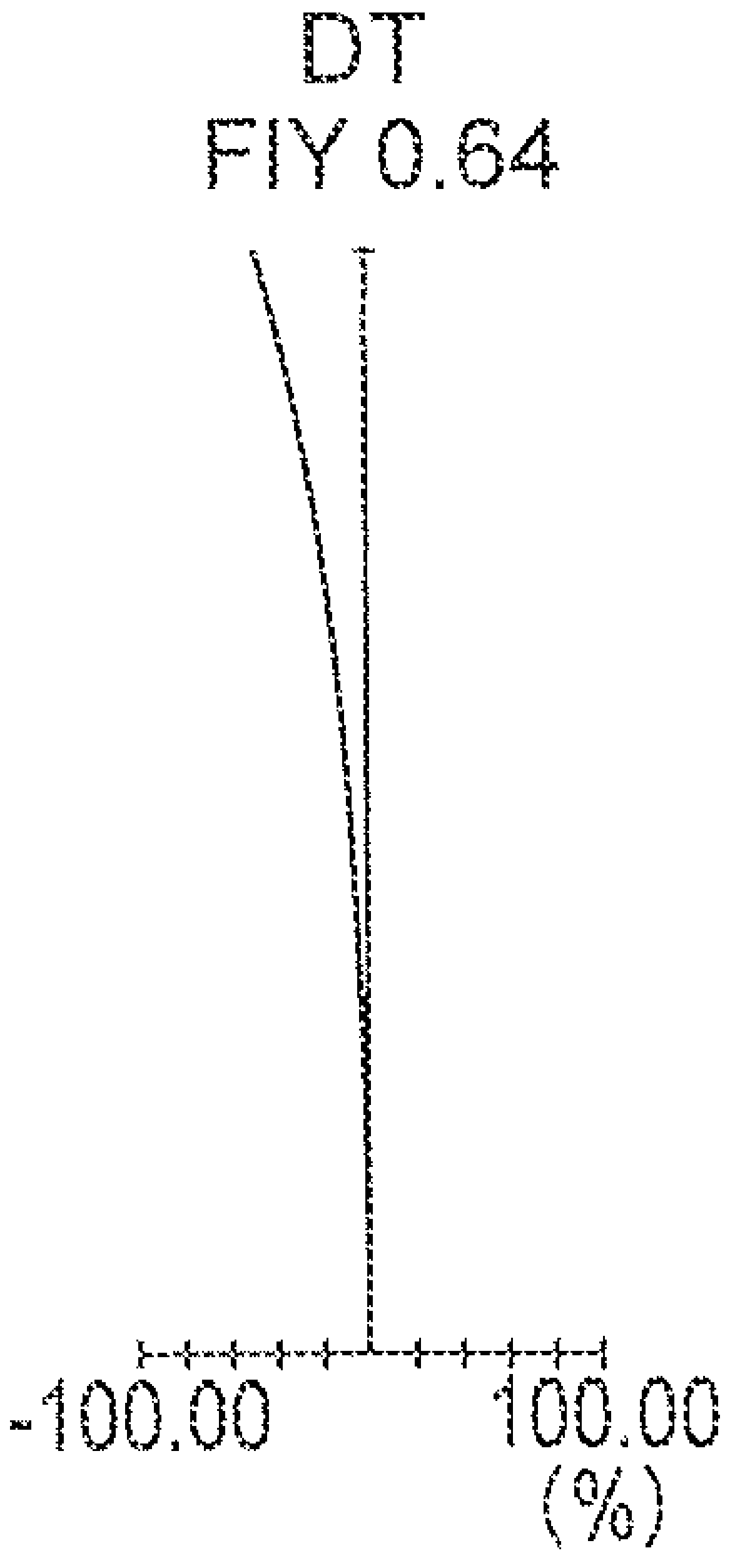


FIG. 29

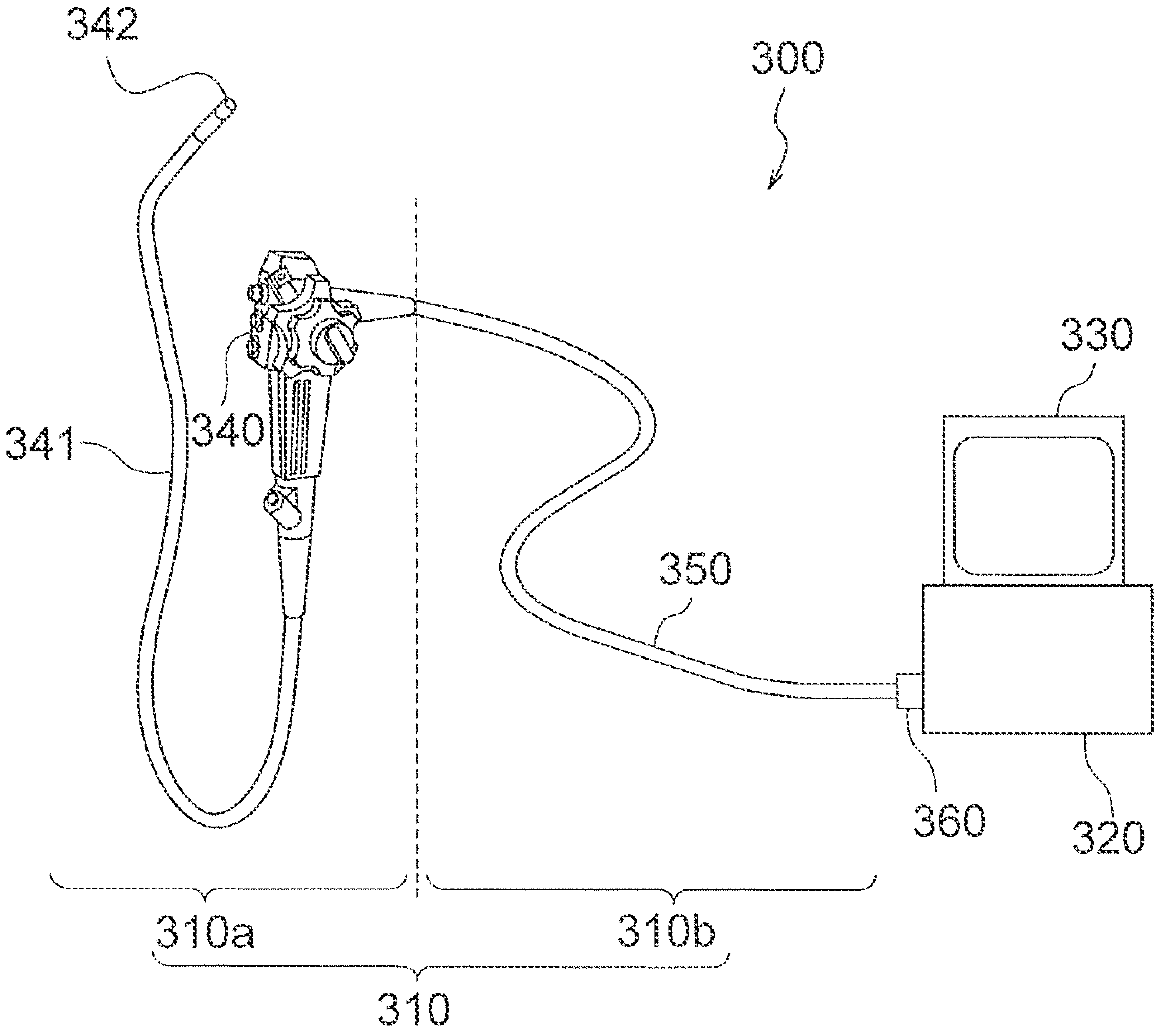


FIG. 30

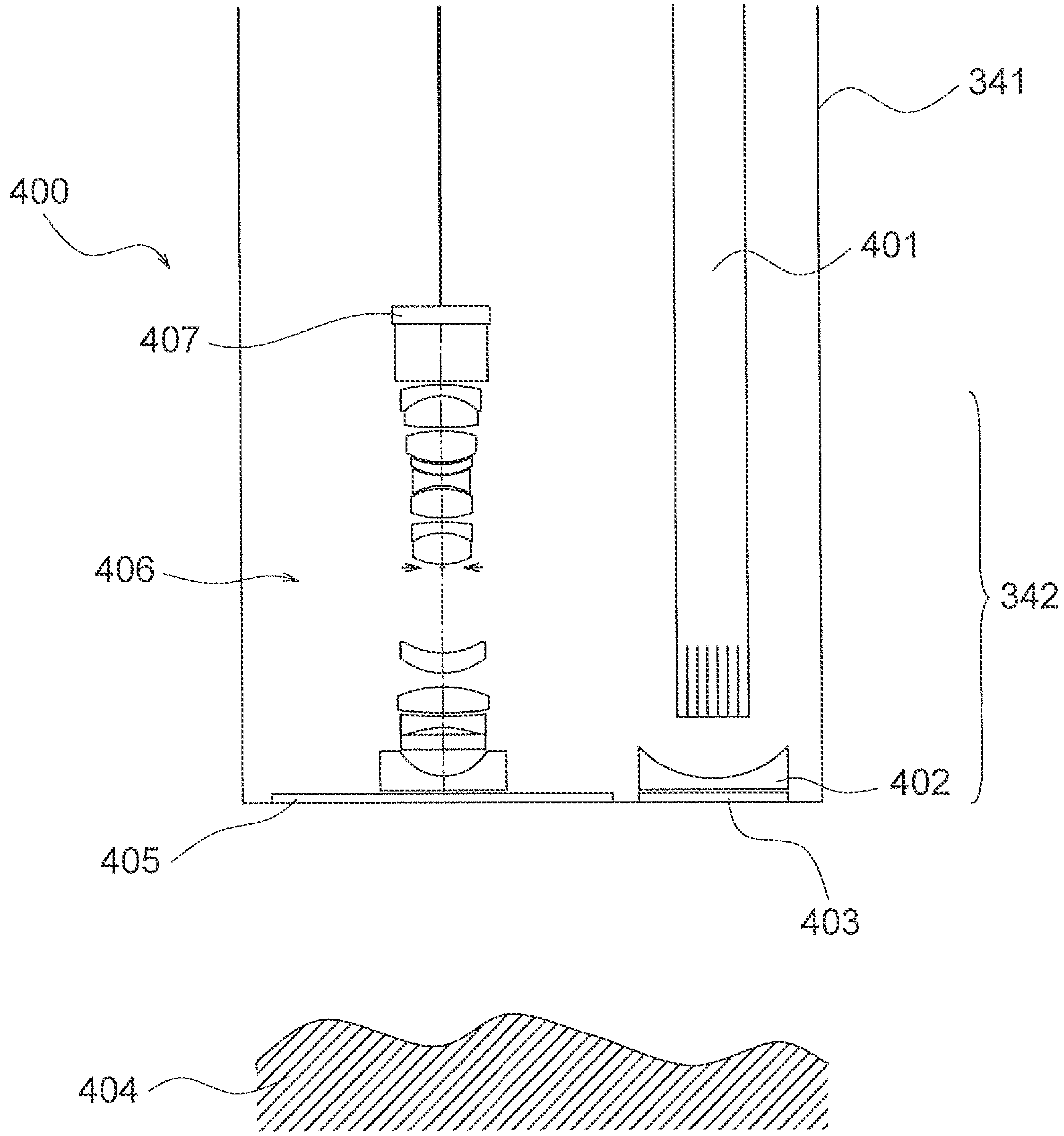


FIG. 31

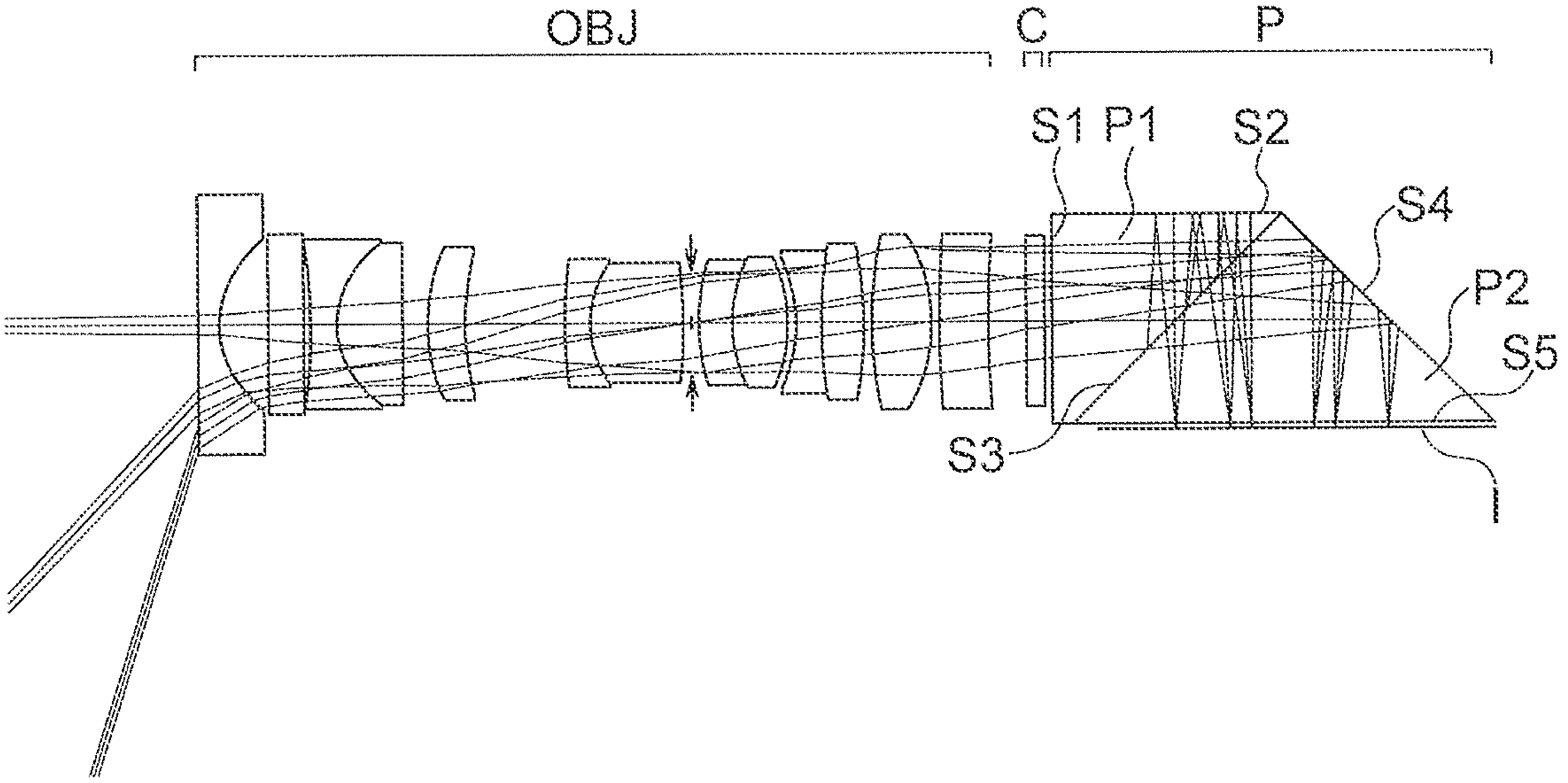


FIG. 32A

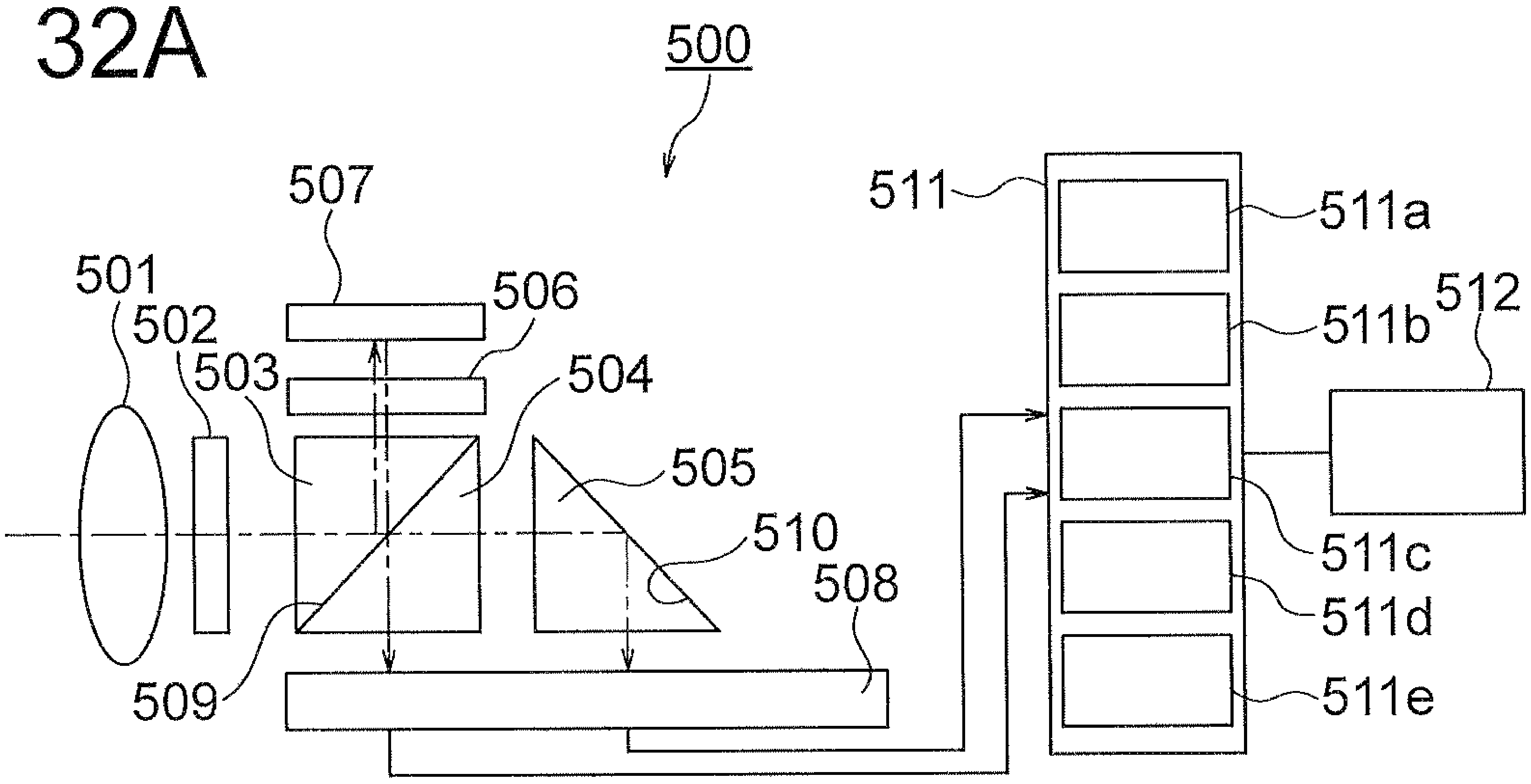


FIG. 32B

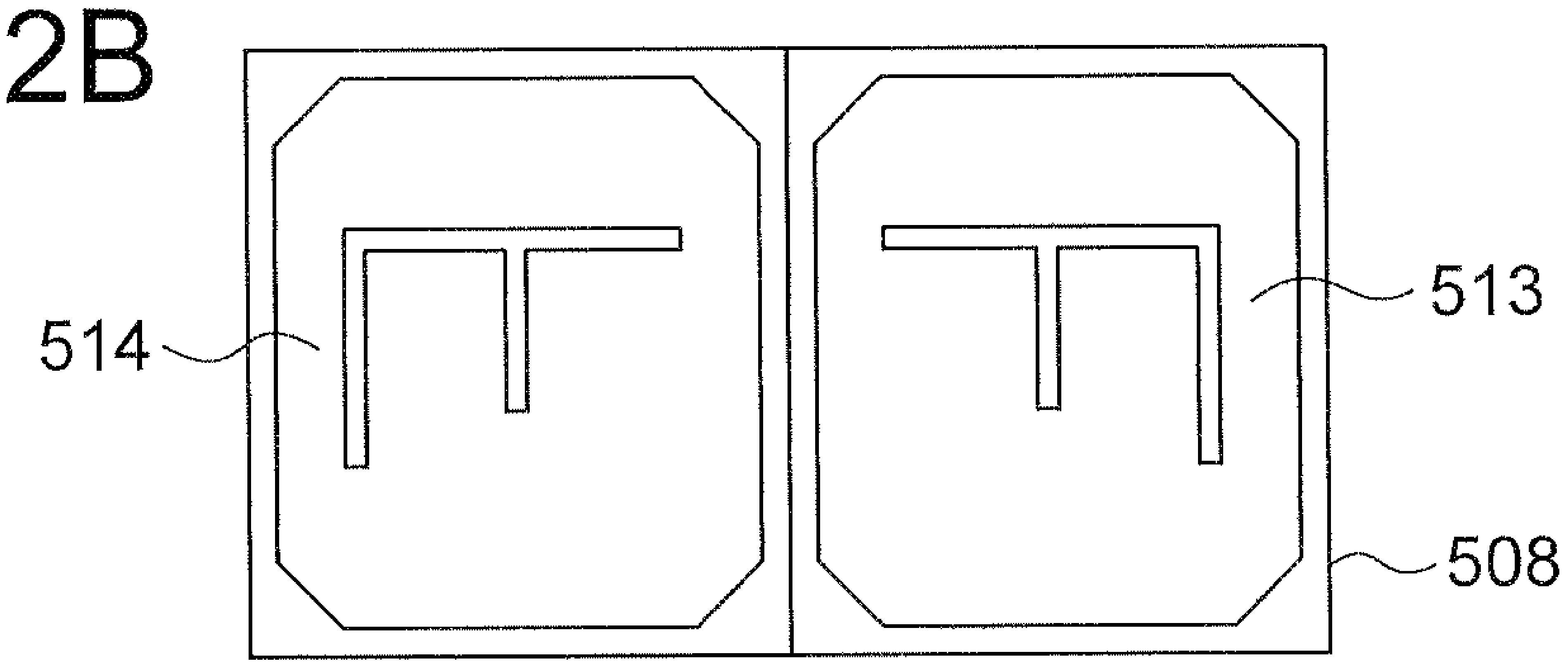
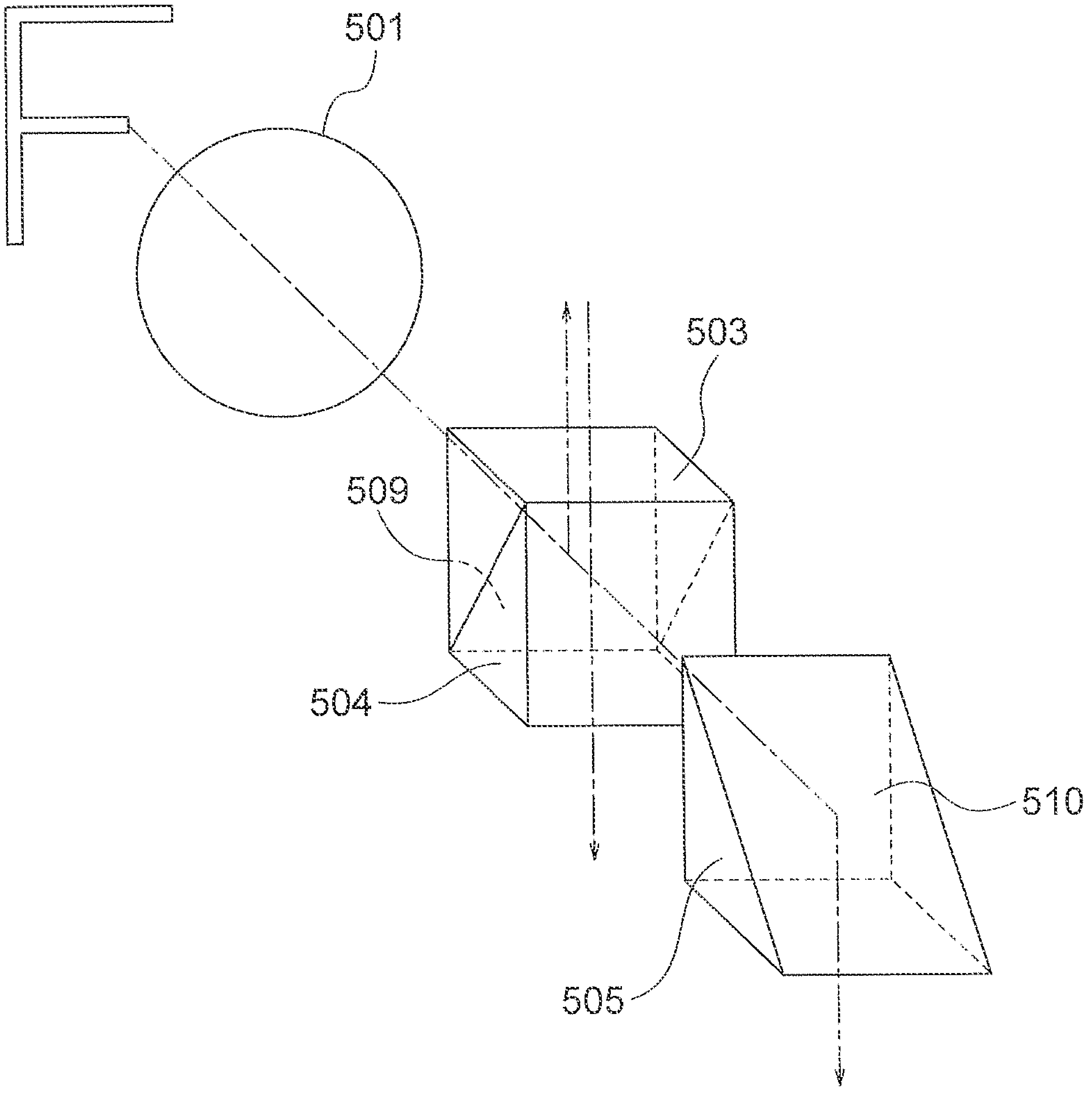


FIG. 33



# WIDE-ANGLE OPTICAL SYSTEM AND IMAGE PICKUP APPARATUS USING THE SAME

## CROSS-REFERENCE TO RELATED APPLICATION

The present application is a continuation application of International Application No. PCT/JP2019/008033 filed on Mar. 1, 2019, the entire contents of which are incorporated herein by reference.

## BACKGROUND

### Technical Field

The present disclosure relates to a wide-angle optical system and an image pickup apparatus using the same.

As an optical system having a wide angle of view, an objective optical system for endoscope has been known. In the objective optical system for endoscope, a wide-angle optical system with the angle of view of more than 100 degrees has been used.

In conventional endoscopes, an image sensor with a small number of pixels was used. Therefore, in an objective optical system for endoscope, an optical system with a fixed focus was used. Even when the optical system with a fixed focus was used, it was possible to cover a range of an object distance required to be observed (observation depth), by a depth of field.

However, in recent years, for improving a quality of an observed image, an image sensor with a large number of pixels has been used. In an endoscope in which the image sensor with a large number of pixels is used, a high resolution is sought even for the optical system.

When an optical system is made to have a high resolution, the depth of field becomes narrower than the required observation depth. Consequently, it becomes difficult to observe the required observation depth in a focused state. For such reasons, a need arose to impart a function of adjusting a focal position to an optical system.

An objective optical system for endoscope which enables to adjust the focal position has been known. In this objective optical system for endoscope, an inner focusing has been used for adjusting the focal position. For carrying out the inner focusing, an actuator is provided around an optical system.

An optical unit, for instance, includes an optical system and an actuator. In an endoscope, it is necessary to seal the optical unit. Moreover, the angle of view is 1400 or more, and there are restrictions on a size and an output of the actuator. Therefore, in the focal-position adjustment, it is difficult to move the optical system. A light-weight and space-saving inner focusing is necessary.

Objective optical systems for endoscope in which, the inner focusing is used, have been disclosed in International Unexamined Patent Application Publication No. 2014/129089 and International Unexamined Patent Application Publication No. 2016/067838.

### Description of the Related Art

## SUMMARY

A wide-angle optical system according to at least some embodiments of the present disclosure is a wide-angle optical system having a lens component,

the lens component has a plurality of optical surfaces, and

in the lens component, two optical surfaces are in contact with air, and at least one optical surface is a curved surface, includes in order from an object side:

a first lens unit having a negative refractive power,

a second lens unit having a positive refractive power, and

a third lens unit having a positive refractive power, wherein

at the time of carrying out a focal-position adjustment from a far point to a near point, the second lens unit is moved from a first position toward a second position, the first position is a position at which a distance between the first lens unit and the second lens unit becomes the minimum, and the second position is a position at which a distance between the second lens unit and the third lens unit becomes the minimum,

the third lens unit includes not less than three lens components,

not less than three lens components include a first lens component and a second lens component, the first lens component is a lens component located nearest to an object in the third lens unit, and the second lens component is a lens component located second from the object side in the third lens unit,

each of the first lens component and the second lens component has a positive refractive power, and

following conditional expression (1) is satisfied:

$$0.8<f3L12/fL<6.0 \qquad (1)$$

where,

f3L12 denotes a combined focal length of the first lens component and the second lens component, and

fL denotes a focal length of the wide-angle optical system at the first position. surface.

Moreover, an image pickup apparatus of the present disclosure includes:

an optical system, and

an image sensor which is disposed on an image plane, wherein

the image sensor has an image pickup surface, and converts an image formed on the image pickup surface by the optical system to an electric signal, and

the optical system is the abovementioned wide-angle optical system.

## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1**A and FIG. **1**B are lens cross-sectional views of a wide-angle optical system of an example 1;

FIG. **2**A and FIG. **2**B are lens cross-sectional views of a wide-angle optical system of an example 2;

FIG. **3**A and FIG. **3**B are lens cross-sectional views of a wide-angle optical system of an example 3;

FIG. **4**A and FIG. **4**B are lens cross-sectional views of a wide-angle optical system of an example 4;

FIG. **5**A and FIG. **5**B are lens cross-sectional views of a wide-angle optical system of an example 5;

FIG. **6**A and FIG. **6**B are lens cross-sectional views of a wide-angle optical system of an example 6;

FIG. **7**A and FIG. **7**B are lens cross-sectional views of a wide-angle optical system of an example 7;

FIG. **8**A and FIG. **8**B are lens cross-sectional views of a wide-angle optical system of an example 8;

FIG. **9**A and FIG. **9**B are lens cross-sectional views of a wide-angle optical system of an example 9;

FIG. **10**A and FIG. **10**B are lens cross-sectional views of a wide-angle optical system of an example 10;

FIG. **11**A and FIG. **11**B are lens cross-sectional views of a wide-angle optical system of an example 11;

FIG. **12**A and FIG. **12**B are lens cross-sectional views of a wide-angle optical system of an example 12;

FIG. **13**A and FIG. **13**B are lens cross-sectional views of a wide-angle optical system of an example 13;

FIG. **14**A and FIG. **14**B are lens cross-sectional views of a wide-angle optical system of an example 14;

FIG. **15**A, FIG. **15**B, FIG. **15**C, FIG. **15**D, FIG. **15**E, FIG. **15**F, FIG. **15**G, and FIG. **15**H are aberration diagrams of the wide-angle optical system of the example 1;

FIG. **16**A, FIG. **16**B, FIG. **16**C, FIG. **16**D, FIG. **16**E, FIG. **16**F, FIG. **16**G, and FIG. **16**H are aberration diagrams of the wide-angle optical system of the example 2;

FIG. **17**A, FIG. **17**B, FIG. **17**C, FIG. **17**D, FIG. **17**E, FIG. **17**F, FIG. **17**G, and FIG. **17**H aberration diagrams of the wide-angle optical system of the example 3;

FIG. **18**A, FIG. **18**B, FIG. **18**C, FIG. **18**D, FIG. **18**E, FIG. **18**F, FIG. **18**G, and FIG. **18**H are aberration diagrams of the wide-angle optical system of the example 4;

FIG. **19**A, FIG. **19**B, FIG. **19**C, FIG. **19**D, FIG. **19**E, FIG. **19**F, FIG. **19**G, and FIG. **19**H are aberration diagrams of the wide-angle optical system of the example 5;

FIG. **20**A, FIG. **20**B, FIG. **20**C, FIG. **20**D, FIG. **20**E, FIG. **20**F, FIG. **20**G, and FIG. **20**H are aberration diagrams of the wide-angle optical system of the example 6;

FIG. **21**A, FIG. **21**B, FIG. **21**C, FIG. **21**D, FIG. **21**E, FIG. **21**F, FIG. **21**G, and FIG. **21**H are aberration diagrams of the wide-angle optical system of the example 7;

FIG. **22**A, FIG. **22**B, FIG. **22**C, FIG. **22**D, FIG. **22**E, FIG. **22**F, FIG. **22**G, and FIG. **22**H are aberration diagrams of the wide-angle optical system of the example 8;

FIG. **23**A, FIG. **23**B, FIG. **23**C, FIG. **23**D, FIG. **23**E, FIG. **23**F, FIG. **23**G, and FIG. **23**H are aberration diagrams of the wide-angle optical system of the example 9;

FIG. **24**A, FIG. **24**B, FIG. **24**C, FIG. **24**D, FIG. **24**E, FIG. **24**F, FIG. **24**G, and FIG. **24**H are aberration diagrams of the wide-angle optical system of the example 10;

FIG. **25**A, FIG. **25**B, FIG. **25**C, FIG. **25**D, FIG. **25**E, FIG. **25**F, FIG. **25**G, and FIG. **25**H are aberration diagrams of the wide-angle optical system of the example 11;

FIG. **26**A, FIG. **26**B, FIG. **26**C, FIG. **26**D, FIG. **26**E, FIG. **26**F, FIG. **26**G, and FIG. **26**H are aberration diagrams of the wide-angle optical system of the example 12;

FIG. **27**A, FIG. **27**B, FIG. **27**C, FIG. **27**D, FIG. **27**E, FIG. **27**F, FIG. **27**G, and FIG. **27**H are aberration diagrams of the wide-angle optical system of the example 13;

FIG. **28**A, FIG. **28**B, FIG. **28**C, FIG. **28**D, FIG. **28**E, FIG. **28**F, FIG. **28**G, and FIG. **28**H are aberration diagrams of the wide-angle optical system of the example 14;

FIG. **29** is a diagram showing a schematic configuration of an endoscope system;

FIG. **30** is a diagram showing an arrangement of an optical system of an endoscope;

FIG. **31** is a diagram showing an arrangement of an optical system of an image pickup apparatus;

FIG. **32**A is a diagram showing a schematic configuration of an image pickup apparatus;

FIG. **32**B is a diagram showing orientations of images on an image sensor; and

FIG. **33** is a diagram showing a positional relationship of an object, an objective optical system, and an optical-path splitting element.

## DETAILED DESCRIPTION

Prior to the explanation of examples, action and effect of embodiments according to certain aspects of the present disclosure will be described below. In the explanation of the action and effect of the embodiments concretely, the explanation will be made by citing concrete examples. However, similar to a case of the examples to be described later, aspects exemplified thereof are only some of the aspects included in the present disclosure, and there exists a large number of variations in these aspects. Consequently, the present disclosure is not restricted to the aspects that will be exemplified.

A wide-angle optical system of the present embodiment is a wide-angle optical system having a lens component. The lens component has a plurality of optical surfaces, and in the lens component, two optical surfaces are in contact with air, and at least one optical surface is a curved surface. The wide-angle optical system includes in order from an object side, a first lens unit having a negative refractive power, a second lens unit having a positive refractive power, and a third lens unit having a positive refractive power. At the time of adjusting a focal-position from a far point to a near point, the second lens unit is moved from a first position toward a second position. The first position is a position at which a distance between the first lens unit and the second lens unit becomes the minimum, and the second position is a position at which a distance between the second lens unit and the third lens unit becomes the minimum. The third lens unit includes not less than three lens components, and not less than three lens components include a first lens component and a second lens component. The first lens component is a lens component located nearest to an object in the third lens unit, and the second lens component is a lens component located second from the object side in the third lens unit. Each of the first lens component and the second lens component has a positive refractive power, and following conditional expression (1) is satisfied:

$$0.8<f3L12/fL<6.0 \qquad (1)$$

where,

f3L12 denotes a combined focal length of the first lens component and the second lens component, and

fL denotes a focal length of the wide-angle optical system at the first position.

The wide-angle optical system of the present embodiment, for instance, is about a wide-angle optical system with an angle of view of more than 100 degrees. In recent years, with the debut of a high-resolution monitor and the like, regarding an image quality at the time of observation, a high image quality is being sought. The wide-angle optical system of the present embodiment is a wide-angle optical system which is capable of dealing with such requirement.

Moreover, the wide-angle optical system of the present embodiment is an optical system in which an inner focusing is used. Therefore, an actuator is disposed around an inner-focusing lens. In the wide-angle optical system of the present embodiment, even with the actuator disposed around the optical system, an outer diameter of the overall optical system is small. The wide-angle optical system of the present embodiment, while being an optical system having a wide angle of view, is an optical system in which a light-ray height is suppressed to be low over a long range of a central portion of the optical system.

The wide-angle optical system of the present embodiment is a wide-angle optical system having the lens component. The lens component has the plurality of optical surfaces. In the lens component, the two optical surfaces are in contact with air, and at least one optical surface is a curved surface. The lens component includes a single lens and a cemented lens for example.

Moreover, in the lens component, a lens and a plane parallel plate may have been cemented. In this case, one optical surface in contact with air is a lens surface, and the other optical surface in contact with air is a flat surface. A lens component in which a single lens and a plane parallel plate are cemented, is to be deemed as a single lens. A lens component in which a cemented lens and a plane parallel plate are cemented, is to be deemed as a cemented lens.

Moreover, a planoconvex lens and a planoconcave lens may have been cemented. In this case, a cemented surface is a curved surface and an optical surface in contact with air is a flat surface.

The surface on the object side of the lens component, out of the two optical surfaces in contact with air, is an optical surface located on the object side. A surface on an image side of the lens component, out of the two optical surfaces in contact with air, is an optical surface located on the image side. In a case in which the lens component is a cemented lens, a cemented surface is located between the surface on the object side and the surface on the image side.

The wide-angle optical system of the present embodiment includes in order from the object side, the first lens unit having a negative refractive power, the second lens unit having a positive refractive power, and the third lens unit having a positive refractive power. At the time of carrying out the focal-position adjustment from the far point to the near point, the second lens unit is moved from the first position toward the second position. The movement from the first position toward the second position is a movement in a direction in which the distance between the first lens unit and the second lens unit widens, and is a movement in a direction in which the distance between the second lens unit and the third lens unit shortens.

The first position is a position at which the distance between the first lens unit and the second lens unit becomes the minimum. At the first position, the second lens unit is located nearest to the object in a range of movement. At the first position, it is possible to focus to an object located at a far point.

The second position is a position at which the distance between the second lens unit and the third lens unit becomes the minimum. At the second position, the second lens unit is located nearest to an image in a range of movement. At the second position, it is possible to focus to an object located at a near point.

The third lens unit includes not less than three lens components. Not less than three lens components include the first lens component and the second lens component. The first lens component is a lens component located nearest to the object in the third lens unit. The second lens component is a lens component located second from the object side in the third lens unit.

In the wide-angle optical system of the present embodiment, each of the first lens component and the second lens component has a positive refractive power. Moreover, the wide-angle optical system of the present embodiment has an image-side lens component. Accordingly, it is possible to realize a wide-angle optical system in which an angle of view is large, and an aberration within a range of adjustment of the focal-position is corrected favorably, and which has a high resolution. Moreover, by the optical system having the high resolution, even when an image sensor with a large number of pixels is used, it is possible to acquire a sharp image corresponding to the large number of pixels.

The second lens unit is moved for the focal-position adjustment. An actuator is used for moving the second lens unit. The actuator is disposed near the second lens unit or near the third lens unit. Therefore, it is necessary to provide a space for disposing the actuator near the second lens unit or near the third lens unit.

By disposing two lens components having a positive refractive power in the third lens unit, it is possible to lower a light-ray height over a wide range from the object side of the second lens unit up to a vicinity of a center of the third lens unit (hereinafter, referred to as 'predetermined range').

By satisfying conditional expression (1), it is possible to lower the light-ray height in the predetermined range. Consequently, it is possible to make small an outer diameter of the second lens unit and an outer diameter of a part of the third lens unit. As a result, it is possible to suppress an increase in an outer diameter of an optical unit even when the actuator is disposed.

By making the combined focal length of the first lens component and the second component small, it is possible to suppress the light-ray height to be low in the predetermined range. However, since a combined refractive power of the first lens component and the second lens component becomes large, an aberration becomes large. Therefore, it is preferable to set appropriately the combined focal length of the first lens component and the second lens component.

In a case in which a value exceeds an upper limit value of conditional expression (1), it becomes difficult to suppress the light-ray height to be low in the predetermined range. In a case in which the value falls below a lower limit value of conditional expression (1), correction of a spherical aberration and correction of a coma become difficult.

It is preferable that following conditional expression (1') be satisfied instead of conditional expression (1).

$$1.0<f3L12/fL<5.2 \tag{1'}$$

Moreover, it is more preferable that following conditional expression (1") be satisfied instead of conditional expression (1).

$$1.2<f3L12/fL<4.8 \tag{1''}$$

The wide-angle optical system of the present embodiment may have an image-side lens component. The image-side lens component, among the plurality of lens components, is a lens component located nearest to an image. The image-side lens component may be a single lens, and may be a lens component which is located nearest to the image among the plurality of lens components.

In a case in which the wide-angle optical system of the present embodiment includes the first lens unit, the second lens unit, and the third lens unit, the image-side lens component is a lens component located nearest to the image in the third lens unit.

In the wide-angle optical system of the present embodiment, it is preferable that not less than two diverging surfaces be disposed between a surface nearest to the object of the first lens component and a surface nearest to the image of the second lens component.

By making such arrangement, it is possible to maintain favorably the imaging performance while maintaining the light-ray height in the predetermined range low.

In the wide-angle optical system of the present embodiment, it is preferable that the third lens unit include not less than three cemented surfaces, and a value of a difference between refractive indices be not less than 0.25 at not less than three cemented surfaces respectively.

Here, the difference in refractive indices is a difference between an object-side refractive index and an image-side refractive index,

- the object-side refractive index is a refractive index for a d-line of a medium which is located on an object side of the cemented surface, and which is adjacent to the cemented surface, and
- the image-side refractive index is a refractive index for a d-line of a medium which is located on an image side of the cemented surface, and which is adjacent to the cemented surface.

By making such arrangement, it is possible to maintain favorably the imaging performance while maintaining the light-ray height in the predetermined range low.

In the wide-angle optical system of the present embodiment, it is preferable that the third lens unit include not less than four lens components, and have not less than two cemented surfaces for which a value of a difference in refractive index is not less than 0.25.

Here, the difference in refractive index is a difference between an object-side refractive index and an image-side refractive index, and

- the object-side refractive index is a refractive index for the d-line of a medium which is located on the object side of a cemented surface, and which is adjacent to the cemented surface, and
- the image-side refractive index is a refractive index for the d-line of a medium which is located on the image side of the cemented surface, and which is adjacent to the cemented surface.

By making such arrangement, it is possible to maintain favorably the imaging performance while maintaining the light-ray height in the predetermined range low.

In the wide-angle optical system of the present embodiment, it is preferable that the third lens unit include three, four, or five lens components having a positive refractive power.

By making such arrangement, it is possible to maintain favorably the imaging performance while maintaining the light-ray height in the predetermined range low.

In the wide-angle optical system of the present embodiment, it is preferable that a cemented lens located nearest to an image in the third lens unit include in order from the object side, a positive lens and a negative lens.

By making such arrangement, it is possible to maintain favorably the imaging performance while maintaining the light-ray height in the predetermined range low.

In the wide-angle optical system of the present embodiment, it is preferable that a single lens unit be disposed nearest to the image in the third lens unit, the single lens unit include two single lenses or three single lenses, a cemented lens be disposed adjacent to the single lens unit, on the object side of the single lens unit, and the cemented lens include in order from the object side, a positive lens and a negative lens.

By making such arrangement, it is possible to maintain favorably the imaging performance while maintaining the light-ray height in the predetermined range low.

In the wide-angle optical system of the present embodiment, it is preferable that one single lens be disposed nearest to the image in the third lens unit, a cemented lens be disposed adjacent to the single lens, on the object side of the single lens, and the cemented lens include in order from the object side, a positive lens and a negative lens.

By making such arrangement, it is possible to maintain favorably the imaging performance while maintaining the light-ray height in the third

In the wide-angle optical system of the present embodiment, it is preferable that following conditional expression (2) be satisfied:

$$0.05 < fL/R31F < 1.20 \qquad (2)$$

where,

R31F denotes a radius of curvature of a surface on the object side of the first lens component, and

fL denotes the focal length of the wide angle-optical system at the first position.

Conditional expression (2) is a conditional expression in which a convergence of a surface nearest to the object in the third lens unit is regulated. The first lens component is located nearest to the object in the third lens unit. Accordingly, conditional expression (2) is a conditional expression in which the convergence of a surface on the object side of the first lens component is regulated.

The larger the curvature of a lens surface, the stronger is the convergence of light rays at the lens surface. The surface on the object side of the first lens component is located nearest to the object in the third lens unit. By making a curvature of the surface on the object side of the first lens component of an appropriate size, it is possible to suppress the light-ray height at the third lens unit to be low.

In a case in which a value exceeds an upper limit value of conditional expression (2), the spherical aberration and the coma are susceptible to occur, or a manufacturing error sensitivity is susceptible to become high. Even when an image sensor with a large number of pixels is used, acquiring a sharp image corresponding to the large number of pixels becomes difficult. Moreover, securing the desired back focus also becomes difficult. In a case in which the value falls below a lower limit value of conditional expression (2), the light-ray height becomes high. Consequently, in a case in which the wide-angle optical system of the present embodiment is used for an optical system of an endoscope, a diameter of an insertion portion becomes large.

It is preferable that following conditional expression (2') be satisfied instead of conditional expression (2).

$$0.07 < fL/R31F < 0.85 \qquad (2')$$

It is more preferable that following conditional expression (2") be satisfied instead of conditional expression (2).

$$0.08 < fL/R31F < 0.75 \qquad (2")$$

An optical system which satisfies conditional expression (2) has a value smaller than an upper limit value. As the value for the optical system becomes smaller, it becomes easier to correct an aberration or it becomes easier to secure a desired back focus in that optical system.

For conditional expression (2), it is possible to set a favorable upper limit value. It is preferable to set the upper limit value to any of 0.60252, 0.55, 0.50, and 0.45. By making such arrangement, it is possible to carry out a favorable aberration correction.

In a case in which favorable aberration correction is to be prioritized, or in a case in which securing the desired back focus is to be prioritized, from 0.10 up to 0.40 can be said to the most appropriate range for conditional expression (2). In a case in which securing a low light-ray height in the predetermined range is to be prioritized, from 0.35 up to 0.65 can be said to be the most appropriate range for conditional expression (2).

It is preferable that the wide-angle optical system of the present embodiment include an image-side lens component, the image-side lens component, among the plurality of lens components, be a lens component located nearest to the image, the third lens unit include N number of cemented surfaces $S_{Ni}$ (i=1, 2, . . . N) between the first lens component and the image-side lens component, and following conditional expression (3) be satisfied:

$$-1.0<fL\times\Sigma P_{SNi}<-0.05 \quad (3)$$

where,

$P_{SNi}$ denotes a refractive power of the cemented surface $S_{Ni}$, and is expressed by following conditional expression (4)

$$P_{SNi}=(n_{SNi}'-n_{SNi})/r_{SNi} \quad (4)$$

where,

$n_{SNi}$ denotes a refractive index for the d-line of a medium located on the object side of the cemented surface $S_{Ni}$,

$n_{SNi}'$ denotes a refractive index for the d-line of a medium located on the image side of the cemented surface $S_{Ni}$,

$r_{SNi}$ denotes a radius of curvature near an optical axis of the cemented surface $S_{Ni}$, and

fL denotes the focal length of the wide-angle optical system at the first position.

Conditional expression (3) is a conditional expression in which the refractive power of the cemented surface in the third lens unit is regulated. In the predetermined range, it is necessary to maintain a state in which a light-beam diameter is thinned. On the other hand, securing a paraxial amount, such as, securing the focal length or securing the back focus, is significant.

For lowering the light-ray height in the predetermined range, in the third lens unit, the lens component located on the object side is made to have a strong convergence. For securing the paraxial amount, it is preferable to dispose a lens component having a strong divergence on an image side of the lens component located on the object side.

In the wide-angle optical system of the present embodiment, the third lens unit includes N number of cemented surfaces $S_{Ni}$. The cemented surface $S_{Ni}$ has a strong divergence. Therefore, conditional expression (3) can be said to be a conditional expression in which the divergence of a light ray on the image side of the predetermined range is regulated.

In a case in which a value exceeds an upper limit value of conditional expression (3), the divergence of a light ray on the image side of the predetermined range becomes weak. Consequently, securing the desired paraxial amount becomes difficult or securing the low light-ray height in the predetermined range becomes difficult.

On the other hand, in a case in which the value falls below a lower limit value of conditional expression (3), a spherical aberration and a coma are susceptible to occur or a manufacturing error sensitivity is susceptible to become high. Even when an image sensor with a large number of pixels is used, it becomes difficult to acquire a sharp image corresponding to the large number of pixels.

It is preferable that following conditional expression (3') be satisfied instead of conditional expression (3).

$$-0.85<fL\times\Sigma P_{SNi}<-0.1 \quad (3')$$

Moreover, it is more preferable that following conditional expression (3") be satisfied instead of conditional expression (3).

$$-0.75<fL\times\Sigma P_{SNi}<-0.1 \quad (3'')$$

For conditional expression (3), it is possible to set a favorable lower limit value. It is preferable to set the lower limit value to any of −0.71861, −0.65, −0.60, and −0.55. By making such arrangement, it is possible to carry out a favorable aberration correction.

In a case in which favorable aberration correction is to be prioritized, from −0.50 up to −0.20 can be said to be the most appropriate range for conditional expression (3). In a case in which securing the low light-ray height in the predetermined range is to be prioritized, from −0.70 up to −0.40 can be said to be the most appropriate range for conditional expression (3).

By satisfying conditional expression (2) or by satisfying conditional expression (3), it is possible to secure the low light-ray height in the predetermined range or to secure the desired paraxial amount easily. It is even more preferable that both of conditional expression (2) and conditional expression (3) be satisfied.

However, when both of conditional expression (2) and conditional expression (3) are satisfied, correction of an astigmatism is susceptible to be difficult. Therefore, in the third lens unit, it is necessary to correct favorably the astigmatism as well.

As mentioned above, $n_{SNi}$ and $n_{SNi'}$ denote the refractive index. More elaborately, $n_{SNi}$ denotes the refractive index for the d-line of the medium which is located on the object side of the cemented surface $S_{Ni}$ and which is adjacent to the cemented surface $S_{Ni}$, and $n_{SNi'}$ denotes the refractive index for the d-line of the medium which is located on the image side of the cemented surface $S_{Ni}$ and which is adjacent to the cemented surface $S_{Ni}$.

In the wide-angle optical system of the present embodiment, it is preferable that the third lens unit include a cemented lens which is located nearest to the image among the cemented lenses, and a positive single lens which is located nearest to the image, the cemented lens which is located nearest to the image have a positive refractive power, and the positive single lens satisfy following conditional expression (5):

$$-2<(R_{3R1}+R_{3R2})/(R_{3R1}-R_{3R2})<2 \quad (5)$$

where,

$R_{3R1}$ denotes a radius of curvature of a surface on the object side of the positive single lens, and

$R_{3R2}$ denotes a radius of curvature of a surface on the image side of the positive single lens.

The third lens unit has the cemented lens which is located nearest to image (hereinafter, referred to as 'cemented lens A'). In a case in which there is one cemented lens disposed in the third lens unit, the cemented lens corresponds to the cemented lens A.

When an optical system is divided into two, an object side and an image side, with a center of the optical system as a boundary between the two, the cemented lens A is located on the image side. In a case in which significance is to be placed on securing an appropriate back focus, the refractive power of the cemented lens A may be made a positive refractive power.

In this case, not only in the object side of the optical system but also in the image side of the optical system, a large positive refractive power is required. For this, it is preferable to make the lens component located nearest to the image a positive single lens, as well as to satisfy conditional expression (5). By making such arrangement, it is possible to suppress the occurrence of astigmatism.

It is preferable that following conditional expression (5') be satisfied instead of conditional expression (5).

$$-1.5<(R_{3R1}+R_{3R2})/(R_{3R1}-R_{3R2})<1.0 \quad (5')$$

It is more preferable that following conditional expression (5") be satisfied instead of conditional expression (5).

$$-1.1<(R_{3R1}+R_{3R2})/(R_{3R1}-R_{3R2})<0.0 \quad (5'')$$

In the wide-angle optical system of the present embodiment, it is preferable that the third lens unit include a cemented lens which is located nearest to the image among the cemented lenses, and a positive single lens which is located nearest to the image, the cemented lens which is located nearest to the image have a negative refractive power, and the positive single lens satisfy following conditional expression (6) be satisfied:

$$-5<('R_{3R1}+'R_{3R2})/('R_{3R1}-'R_{3R2})<1 \quad (6)$$

where,

$'R_{3R1}$ denotes a radius of curvature of a surface on the object side of the positive single lens, and

$'R_{3R2}$ denotes a radius of curvature of a surface on the image side of the positive single lens.

There is case in which significance is to be placed on shortening an overall length of the optical system, rather than on securing the appropriate back focus. In this case, since a large positive refractive power becomes necessary on the object side of the optical system, a large negative refractive power becomes necessary on the image side of the optical system.

The cemented lens A, among the cemented lenses, is located nearest to the image. Therefore, by making the refractive power of the cemented lens A a negative refractive power, it is possible to achieve a large negative refractive power on the image side. However, when such an arrangement is made, the astigmatism is susceptible to occur or an angle of emergence of an off-axis light ray is susceptible to become large.

In this case, it is preferable to make the lens component located nearest to the image a positive single lens, and to satisfy conditional expression (6). By making such arrangement, the positive single lens is disposed on a rear side of the cemented lens having a negative refractive power. Consequently, it is possible to cancel an increase in the astigmatism or to cancel an increase in the angle of emergence of the off-axis light ray.

In a case in which a value exceeds an upper limit value of conditional expression (6), the abovementioned cancellation effect is susceptible to become weak. In a case in which the value falls below a lower limit value of conditional expression (6), there is an increase in the occurrence of astigmatism or it is not possible to secure adequately an effective diameter of the positive single lens. When an attempt is made to secure adequately the effective diameter of the positive single lens, the back focus becomes excessively long. Consequently, the overall length of the optical system becomes long.

At the lens component located nearest to the image in the third lens unit, a light-ray height of the off-axis light ray is high. Consequently, when a cemented lens is used for this lens component, a thickness as a lens component is susceptible to increase. As a result, securing an adequate back focus or shortening the overall length of the optical system becomes difficult.

It is preferable that following conditional expression (6') be satisfied instead of conditional expression (6).

$$-4.7<('R_{3R1}+'R_{3R2})/('R_{3R1}-'R_{3R2})<0.8 \quad (6')$$

Moreover, it is more preferable that following conditional expression (6") be satisfied instead of conditional expression (6).

$$-4.5<('R_{3R1}+'R_{3R2})/('R_{3R1}-'R_{3R2})<0.6 \quad (6'')$$

In the wide-angle optical system of the present embodiment, it is preferable that a cemented surface located nearest to the image in the third lens unit satisfy following conditional expression (7):

$$-2.0<fL/r_{SNr}<1.56 \quad (7)$$

where,

$r_{SNr}$ denotes a radius of curvature near the optical axis of the cemented surface located nearest to the image, and

fL denotes the focal length of the wide-angle optical system at the first position.

On the image side of the predetermined range, it is preferable that the divergence of a light ray be strong. When the divergence of a light ray is strong, a light-ray height of an off-axis light ray is relatively high with respect to a light-ray height of an axial light ray.

When the light-ray height of an off-axis light ray becomes high, an astigmatism is susceptible to become large. For suppressing an increase in the astigmatism, it is preferable to make a cemented surface located nearest to the image in the third lens unit a shape concentric with respect to a pupil of an optical system. By satisfying conditional expression (7), it is possible to suppress the increase in the astigmatism.

In a case in which a value exceeds an upper limit value of conditional expression (7), it becomes difficult to carry out the correction of the astigmatism. In a case in which the value falls below a lower limit value of conditional expression (7), it becomes difficult to carry out the correction of the spherical aberration.

It is preferable that following conditional expression (7') be satisfied instead of conditional expression (7).

$$-1.2<fL/r_{SNr}<1.0 \quad (7')$$

Moreover, it is more preferable that following conditional expression (7") be satisfied instead of conditional expression (7).

$$-0.9<fL/r_{SNr}<0.6 \quad (7'')$$

An optical system which satisfies conditional expression (7) has a value smaller than the upper limit value. As the value in the optical system becomes smaller, it becomes easy to correct the astigmatism in that optical system.

For conditional expression (7), it is possible to set a favorable upper limit value. It is preferable to set the upper limit value to any of −0.32190, −0.35, −0.40, and −0.45. By making such arrangement, it is possible to correct the astigmatism favorably.

In a case in which the correction of the astigmatism is to be prioritized, from −0.80 up to −0.50 can be said to be the most appropriate range for conditional expression (7). In a case in which the correction of the spherical aberration is to be prioritized, from −0.60 up to −0.30 can be said to be the most appropriate range for conditional expression (7).

At the cemented surface located nearest to the mage in the third lens unit, it is preferable that a positive lens be located on the object side of the cemented surface, and a negative lens be located on the image side of the cemented surface.

As a means for simultaneously realizing suppression of the light-ray height in the predetermined range, aberration correction at the time of designing, and prevention of aberration deterioration at the time of manufacturing, improvement of the degree of freedom of a chromatic-aberration correction is given. For improving the degree of freedom of the chromatic-aberration correction, an appropriate medium is to be used for the medium of a lens.

By setting appropriately a curvature and a thickness of a lens, it is possible to correct the spherical aberration, the coma, and the astigmatism favorably, and by selecting an appropriate glass for the medium of a lens, it is possible to correct the chromatic aberration favorably.

For instance, in an endoscope optical system, a thickness of each lens is large with respect to a focal length of the optical system. In such optical system, it is difficult to achieve both of the correction of longitudinal chromatic aberration and the correction of chromatic aberration of magnification, together.

However, in the wide-angle optical system of the present embodiment, the plurality of lens components is disposed in the third lens unit. Accordingly, it is possible to set appropriately the medium of the lens component located on the object side and the medium of the lens component located on the image side. As a result, it is possible to achieve both of the correction of the longitudinal chromatic aberration and the correction of the chromatic aberration of magnification, together.

In the wide-angle optical system of the present embodiment, it is preferable that the third lens unit include a plurality of positive lenses, the plurality of positive lenses include a first positive lens and a second positive lens, the first positive lens, among the plurality of positive lenses, be a positive lens located nearest to the object, the second positive lens, among the plurality of positive lenses, be a positive lens located second from the object, and following conditional expression (8) be satisfied:

$$-70<\nu_{31P}-\nu_{32P}<20 \tag{8}$$

where,

$\nu_{31P}$ denotes an Abbe number for the first positive lens, and

$\nu_{32P}$ denotes an Abbe number for the second positive lens.

Conditional expression (8) is a conditional expression in which a relationship of Abbe number for the first positive lens and Abbe number for the second positive lens is regulated. In a case of satisfying conditional expression (8), in a state of both the correction of the longitudinal chromatic aberration and the correction of the chromatic aberration of magnification achieved together, it becomes easy to satisfy various design conditions of an optical system.

In a case in which a value becomes large on a plus side, for instance, in a case in which the value exceeds an upper limit value of conditional expression (8), the longitudinal chromatic aberration varies in a direction of being corrected excessively, and the chromatic aberration of magnification varies in a direction of being corrected inadequately.

It is preferable that following conditional expression (8') be satisfied instead of conditional expression (8).

$$-65<\nu_{31P}-\nu_{32P}<15 \tag{8'}$$

Moreover, it is more preferable that following conditional expression (8") be satisfied instead of conditional expression (8).

$$-60<\nu_{31P}-\nu_{32P}<10 \tag{8''}$$

An optical system which satisfies conditional expression (8) has a value smaller than the upper limit value. As the value in the optical system becomes smaller, it becomes easy to correct the longitudinal chromatic aberration and the chromatic aberration of magnification in that optical system.

For conditional expression (8), it is possible to set a favorable upper limit value. It is preferable to set the upper limit value to any of 0, −5.0, −10.0, and −15.0. By making such arrangement, it is possible to correct the longitudinal chromatic aberration and the chromatic aberration of magnification favorably. Moreover, from −60.0 up to −20.0 can be said to be the most suitable range from conditional expression (8).

In the wide-angle optical system of the present embodiment, it is preferable that the third lens unit include a plurality of positive lenses, the plurality of positive lenses include a first positive lens, a second positive lens, and a third positive lens, the first positive lens, among the plurality of positive lenses, be a positive lens located nearest to the object, the second positive lens, among the plurality of positive lenses, be a positive lens located second from the object, the third positive lens, among the plurality of positive lenses, be a positive lens located third from the object, and following conditional expression (9) be satisfied:

$$-50<\nu_{33P}-(\nu_{31P}+\nu_{32P})/2<80 \tag{9}$$

where,

$\nu_{31P}$ denotes the Abbe number for the first positive lens,

$\nu_{32P}$ denotes the Abbe number for the second positive lens, and

$\nu_{33p}$ denotes an Abbe number for the third positive lens.

Conditional expression (9) is a conditional expression in which a relationship between an average value of Abbe number for the first positive lens and Abbe number for the second positive lens, and Abbe number for the third positive lens is regulated. In a case of satisfying conditional expression (9), in a state of both the correction of the longitudinal chromatic aberration and the correction of the chromatic aberration of magnification achieved together, it becomes easy to satisfy various design conditions of an optical systems.

In a case in which a value becomes large on a minus side, for instance, in a case in which the value falls below a lower limit value of conditional expression (9), the longitudinal chromatic aberration varies in a direction of being corrected excessively, and the chromatic aberration of magnification varies in a direction of being corrected inadequately.

It is preferable that following conditional expression (9') be satisfied instead of conditional expression (9).

$$-40<\nu_{33P}-(\nu_{31P}+\nu_{32P})/2<70 \tag{9'}$$

Moreover, it is more preferable that following conditional expression (9") be satisfied instead of conditional expression (9).

$$-35\leq\nu_{33P}-(\nu_{31P}+\nu_{32P})/2<60 \tag{9''}$$

For conditional expression (9), it is possible to set a favorable lower limit value. It is preferable to set the lower limit value to any of −22.99, −15.0, −10.0 and −5.0. By making such arrangement, it is possible to correct the longitudinal chromatic aberration and the chromatic aberration of magnification favorably. Moreover, from 0.4 up to 40.0 can be said to be the most suitable range from conditional expression (9).

In the wide-angle optical system of the present embodiment, it is preferable that the third lens unit include a plurality of negative lenses, the plurality of negative lenses include a first negative lens and a second negative lens, the first negative lens, among the plurality of negative lenses, be a negative lens located nearest to the object, the second negative lens, among the plurality of negative lenses, be a negative lens located second from the object, and following conditional expression (10) be satisfied:

$$-40<\nu_{31N}-\nu_{32N}<50 \quad (10)$$

where,

$\nu_{31N}$ denotes an Abbe number for the first negative lens, and

$\nu_{32N}$ denotes an Abbe number for the second negative lens.

Conditional expression (10) is a conditional expression in which a relationship of Abbe number for the first negative lens and Abbe number for the second negative lens is regulated. In case of satisfying conditional expression (10), in a state of both the correction of the longitudinal chromatic aberration and the correction of the chromatic aberration of magnification achieved together, it becomes easy to satisfy various design conditions of an optical systems.

In a case in which a value becomes large on a minus side, for instance, in a case in which the value falls below a lower limit value of conditional expression (10), the longitudinal chromatic aberration varies in a direction of being corrected excessively, and the chromatic aberration of magnification varies in a direction of being corrected inadequately.

It is preferable that following conditional expression (10') be satisfied instead of conditional expression (10).

$$-25<\nu_{31N}-\nu_{32N}<40 \quad (10')$$

Moreover, it is more preferable that following conditional expression (10") be satisfied instead of conditional expression (10).

$$-20<\nu_{31N}-\nu_{32N}<30 \quad (10'')$$

For conditional expression (10), it is possible to set a favorable lower limit value. It is preferable to set the lower limit value to any of −15.34, −12.0, −8.0, and −4.0. By making such arrangement, it is possible to correct the longitudinal chromatic aberration and the chromatic aberration of magnification favorably. Moreover, from 0.0 up to 20.0 can be said to be the most suitable range from conditional expression (10).

In a case in which there is one negative lens in the third lens unit, it is preferable that following conditional expression be satisfied:

$$-40<\nu_N<50$$

where,

$\nu_N$ denotes Abbe's number for the negative lens.

In the wide-angle optical system of the present embodiment, it is preferable that the third lens unit be fixed at the time of carrying out the focal-position adjustment.

In the third lens unit, with respect to an aberration variation, a tendency of a manufacturing error sensitivity becoming high is strong. Even for a small manufacturing error, the aberration varies largely. Therefore, it is preferable to keep the third lens unit fixed at the time of carrying out the focal-position adjustment.

In the wide-angle optical system of the present embodiment, it is preferable that following conditional expression (11) be satisfied:

$$-60<(R21F+R21R)/(R21F-R21R)<1 \quad (11)$$

where,

R21F denotes a radius of curvature of a surface on the object side of a predetermined lens component,

R21R denotes a radius of curvature of a surface on the image side of the predetermined lens component, and the predetermined lens component is a lens component located nearest to the object in the second lens unit.

In a case in which a value exceeds an upper limit value of conditional expression (11), a variation in the spherical aberration at the time of focal-position adjustment or a variation in the astigmatism is susceptible to become large. In a case in which the value falls below a lower limit value of conditional expression (11), a deterioration of the astigmatism and a deterioration of the coma due to decentering are susceptible to occur. As mentioned above, the decentering occurs due to a movement of the second lens unit.

It is preferable that following conditional expression (11') be satisfied instead of conditional expression (11).

$$-40<(R21F+R21R)/(R21F-R21R)<-1 \quad (11')$$

Moreover, it is more preferable that following conditional expression (11") be satisfied instead of conditional expression (11).

$$-30<(R21F+R21R)/(R21F-R21R)<-2 \quad (11'')$$

An optical system which satisfies conditional expression (11) has a value smaller than the upper limit value. As the value in the optical system becomes smaller, it becomes easier to correct the spherical aberration or the astigmatism at the time of focal-position adjustment more favorably in that optical system.

For conditional expression (11), it is possible to set a favorable upper limit value. It is preferable to set the upper limit value to any of 5.33106, 1.0, 0.0, and −1.0. Moreover, from −15.0 up to −2.0 can be said to be the most suitable range from conditional expression (11).

In the wide-angle optical system of the present embodiment, it is preferable that following conditional expression (12) be satisfied:

$$0.2<D21/fL<3.0 \quad (12)$$

where,

D21 denotes a distance on an optical axis between a surface nearest to the object and a surface nearest to the image of the second lens unit, and

fL denotes the focal length of the wide-angle optical system at the first position.

In a case in which a value exceeds an upper limit value of conditional expression (12), a weight of the second lens unit increases or the light-ray height becomes high. As just described, it is susceptible to become disadvantageous from a viewpoint of suppressing the increase in the weight of the second lens unit or suppressing the increase in the light-ray height.

In a case in which the value falls below a lower limit value of conditional expression (12), it becomes difficult to achieve two controls. One control is suppressing the variation in the spherical aberration at the time of focal-position adjustment or suppressing the variation in the astigmatism. The other control is suppressing the deterioration of the coma due to decentering or suppressing the deterioration of the astigmatism. The decentering occurs due to a movement of a moving unit at the time of focal-position adjustment.

It is preferable that following conditional expression (12') be satisfied instead of conditional expression (12).

$$0.3<D21/fL<2.5 \quad (12')$$

Moreover, it is more preferable that following conditional expression (12") be satisfied instead of conditional expression (12).

$$0.4<D21/fL<2.0 \quad (12'')$$

An optical system which satisfies conditional expression (12) has a value larger than the lower limit value. As the value in the optical system becomes larger, it becomes easier to achieve both of the abovementioned controls in that optical system.

For conditional expression (12), it is possible to set a favorable lower limit value. It is preferable to set the lower limit value to any of 0.54857, 0.56, 0.58, and 0.60. Moreover, from 0.60 up to 1.5 can be said to be the most appropriate range for conditional expression (12).

In the wide-angle optical system of the present embodiment, it is preferable that following conditional expression (13) be satisfied:

$$1.01<\beta 2F<1.35 \tag{13}$$

where,

β2F denotes a magnification of the second lens unit at the first position.

In a case in which a value exceeds an upper limit value of conditional expression (13), an amount of focus movement with respect to the amount of movement of the second lens unit (hereinafter, referred to as 'focusing sensitivity') becomes excessively high. In this case, an accuracy at the time of stopping the second lens unit (hereinafter, referred to as 'stopping accuracy') becomes excessively high. Consequently, a moving mechanism becomes complicated.

In a case in which a value falls below a lower limit value of conditional expression (13), the focusing sensitivity is susceptible to become low. In this case, since the amount of movement of the second lens unit increases, a space for the movement has to be made wide. Consequently, an optical unit becomes large.

It is preferable that following conditional expression (13') be satisfied instead of conditional expression (13).

$$1.03<\beta 2F<1.30 \tag{13'}$$

Moreover, it is more preferable that following conditional expression (13") be satisfied instead of conditional expression (13").

$$1.05<\beta 2F<1.25 \tag{13''}$$

In the wide-angle optical system of the present embodiment, it is preferable that following conditional expression (14) be satisfied:

$$1.01<\beta 2N/\beta 2F<1.15 \tag{14}$$

where,

β2F denotes the magnification of the second lens unit at the first position, and

β2N denotes a magnification of the second lens unit at the second position.

In a case in which conditional expression (14) is satisfied, since a focal length at a far point becomes short, it is possible to secure a wide angle of view at a far point. Moreover, since a focal length at a near point becomes long, it is possible to achieve a high magnification at a near point.

An optical system having a wide angle of view at a far point and a high magnification at a near point is appropriate for an optical system of an endoscope. Therefore, it is possible to use the wide-angle optical system of the present embodiment as an optical system for an endoscope.

In an endoscope, for instance, by observing a wide range, it is checked if there is a lesion part. Moreover, when it is confirmed that there is a lesion part, the lesion part is magnified and observed in detail. Therefore, it is preferable that an optical system of an endoscope have a wide angle of view for a far-point observation, and have a high magnification for a near-point observation.

Moreover, in the near-point observation, it is necessary to observe a lesion part in detail. Therefore, in an optical system for an endoscope, it is preferable to have an ability to focus with a high accuracy.

In a case in which a value exceeds an upper limit value of conditional expression (14), the focusing sensitivity at a near-point side becomes high. In this case, the stopping accuracy at the near-point side becomes high. Consequently, it becomes difficult to focus with high accuracy. In a case in which the value falls below a lower limit value of conditional expression (14), securing a wide-angle of view in the far-point observation and securing a high magnification in the near-point observation become difficult. Consequently, it becomes inappropriate for an optical system of an endoscope.

It is preferable that following conditional expression (14') be satisfied instead of conditional expression (14).

$$1.02<\beta 2N/\beta 2F<1.12 \tag{14'}$$

Moreover, it is more preferable that following conditional expression (14") be satisfied instead of conditional expression (14).

$$1.03<\beta 2N/\beta 2F<1.09 \tag{14''}$$

In the wide-angle optical system of the present embodiment, it is preferable that following conditional expression (15) be satisfied:

$$0.08<(1-\beta 2F^2)\times\beta 3F^2<0.45 \tag{15}$$

where,

β2F denotes the magnification of the second lens unit at the first position, and

β3F denotes a magnification of the third lens unit at the first position.

In a case in which a value exceeds an upper limit value of conditional expression (15), the focusing sensitivity at the far-point side becomes excessively high. In this case, the stopping accuracy at the far-point side becomes high. In a case in which the value falls below a lower limit value of conditional expression (15), the focusing sensitivity at the far-point side is susceptible to become low. In this case, since the amount of movement of the second lens unit increases, the space for the movement has to be made wide. Consequently, the optical unit becomes large.

It is preferable that following conditional expression (15') be satisfied instead of conditional expression (15).

$$0.11<(1-\beta 2F^2)\times\beta 3F^2<0.35 \tag{15'}$$

Moreover, it is more preferable that following conditional expression (15") be satisfied instead of conditional expression (15).

$$0.13<(1-\beta 2F^2)\times\beta 3F^2<0.30 \tag{15''}$$

In the wide-angle optical system of the present embodiment, it is preferable that following conditional expression (16) be satisfied:

$$0.15<(1-\beta 2N^2)\times\beta 3N^2<0.55 \tag{16}$$

where,

β2N denotes the magnification of the second lens unit at the second position, and

β3N denotes a magnification of the third lens unit at the second position.

In a case in which a value exceeds an upper limit value of conditional expression (16), the focusing sensitivity at the near-point side becomes excessively high. In this case, the stopping accuracy at the near-point side becomes high. In a case in which the value falls below a lower limit value of conditional expression (16), the focusing sensitivity at the near-point side is susceptible to become low. In this case, since the amount of movement of the second lens unit increases, the space for the movement has to be made wide.

It is preferable that following conditional expression (16') be satisfied instead of conditional expression (16).

$$0.20<(1-\beta 2N^2)\times\beta 3N^2<0.45 \tag{16'}$$

Moreover, it is more preferable that following conditional expression (16") be satisfied instead of conditional expression (16).

$$0.22<(1-\beta 2N^2)\times\beta 3N^2<0.40 \tag{16''}$$

In the wide-angle optical system of the present embodiment, it is preferable that the second lens unit include only a positive lens.

By making such arrangement, it is possible to reduce the variation in the astigmatism at the time of focal-position adjustment.

In the wide-angle optical system of the present embodiment, it is preferable that the first lens unit include only a negative lens, and the negative lens have Abbe number larger than Abbe number for a positive lens nearest to the object in the third lens unit

It is not necessary to dispose an actuator in the first lens unit. However, for securing a wide angle of view, an outer diameter of the first lens unit is susceptible to become large. For making the outer diameter of the first lens unit small, a negative refractive power of the first lens unit is to be made large. When the negative refractive power of the first lens unit is made large, an off-axis aberration, particularly the astigmatism, is susceptible to occur.

By disposing the plurality of negative lenses in the first lens unit, it is possible to distribute the negative refractive power of the first lens unit to the plurality of negative lenses. As a result, even when the negative refractive power of the first lens unit is made large, it is possible to correct the off-axis aberration, particularly the astigmatism, favorably.

For making the light-ray height low in an optical system having an extremely wide angle of view, shortening a distance from a surface of incidence up to an entrance-pupil position as much as possible is effective. For this, not disposing a lens which corrects a chromatic aberration in the first lens unit may be one of the options. In a case in which a lens which corrects the chromatic aberration is not disposed in the first lens unit, the first lens unit includes only the single lens.

In this case, the chromatic aberration of magnification is susceptible to occur in the first lens unit. However, it is possible to correct the chromatic aberration of magnification which occurred in the first lens unit, in the third lens unit. At this time, Abbe number for the negative single lens in the first lens unit is to be made larger than Abbe number for the positive lens nearest to the object in the third lens unit.

The positive lens nearest to the object in the third lens unit is located at a distance closest from the negative lens in the first lens unit. Consequently, correction of the chromatic aberration of magnification becomes possible without the longitudinal chromatic aberration being deteriorated. In a case in which Abbe number for the negative lens in the first lens unit is smaller than Abbe number for the positive lens nearest to the object in the third lens unit, it becomes difficult to carry out correction of the longitudinal chromatic aberration and correction of the chromatic aberration of magnification simultaneously.

In the wide-angle optical system of the present embodiment, it is preferable that first lens unit include a plurality of negative lens components, the plurality of negative lens components include a first negative lens component and a second negative lens component, the second negative lens component, among the plurality of negative lens components, be a negative lens component located second from the object, and following conditional expression (17) be satisfied:

$$-2.0<fL/R12F_a<5.0 \tag{17}$$

where,

$R12F_a$ denotes a radius of curvature of a surface on the object side of the second negative lens component, and

fL denotes the focal length of the wide-angle optical system at the first position.

Since the wide-angle optical system of the present embodiment has a wide angle of view, it is possible to use it for an optical system of an endoscope. In an optical system of an endoscope, from the viewpoint of securing the angle of view, constraints of the aberration correction, and constraints of cleaning, a surface nearest to the object becomes a flat surface or a surface convex toward the object side. Therefore, in the negative lens which is located second from the object side, it is preferable to make an object-side surface a strong diverging surface.

In a case in which a value exceeds an upper limit value of conditional expression (17), the light-ray height in the first lens unit is susceptible to become high. In a case in which the value falls below a lower limit value of conditional expression (17), the astigmatism is susceptible to occur.

The second negative lens component, for instance, is a single lens having a negative refractive power located second from the object or a cemented lens having a negative refractive power located second from the object. In a case in which the second negative lens component is a cemented lens, the cemented lens is formed by a positive lens and a negative lens. The positive lens may be located on the object side and the negative lens may be located on the object side.

It is preferable that following conditional expression (17') be satisfied instead of conditional expression (17).

$$-0.8<fL/R12F_a<0.2 \tag{17'}$$

Moreover, it is more preferable that following conditional expression (17") be satisfied instead of conditional expression (17).

$$-0.6<fL/R12F_a<0.0 \tag{17''}$$

In the wide-angle optical system of the present embodiment, it is preferable that the first lens unit include a fourth lens component and a fifth lens component, the fourth lens component be a lens component located nearest to the object in the first lens unit, the fifth lens component be a lens component located second from the object side in the first lens unit, the fourth lens component include a negative lens component, the fifth lens component include a cemented lens, and following conditional expression (18) be satisfied:

$$-1.0<fL/R12F_b<0.5 \tag{18}$$

where,

$R12F_b$ denotes a radius of curvature of a surface on the object side of the fifth lens component, and

fL denotes the focal length of the wide-angle optical system at the first position.

As mentioned above, in an optical system of an endoscope, the surface located nearest to the object becomes a flat surface or a surface convex toward the object side. Therefore, in the negative lens which located third from the object side, it is preferable to make an object-side surface a strong diverging surface.

In a case in which a value exceeds an upper limit value of conditional expression (18), the light-ray height in the first lens unit is susceptible to become high. In a case in which the value falls below a lower limit value of conditional expression (18), the astigmatism is susceptible to occur.

It is preferable that following conditional expression (18') be satisfied instead of conditional expression (18).

$$-0.8<fL/R12F_b<0.2 \tag{18'}$$

Moreover, it is more preferable that following conditional expression (18") be satisfied instead of conditional expression (18).

$$-0.6<fL/R12F_b<0.0 \tag{18''}$$

In the wide-angle optical system of the present embodiment, it is preferable that the first lens unit include a fourth lens component, a fifth lens component, and a sixth lens component, the fourth lens component be a lens component located nearest to the object in the first lens unit, the fifth lens component be a lens component located second from the object side in the first lens unit, the sixth lens component be a lens component located third from the object side in the first lens unit, the fourth lens component include a negative lens component, the fifth lens component include a negative lens component, and the sixth lens component include a positive lens component, and following conditional expression (19) be satisfied:

$$-1.0<fL/R12F_e<0.4 \tag{19}$$

where,

$R12F_e$ denotes a radius of curvature of a surface on the object side of the fifth lens component, and

fL denotes the focal length of the wide-angle optical system at the first position.

As mentioned above, in an optical system for an endoscope, the surface located nearest to the object becomes a flat surface or a surface convex toward the object side. Therefore, in the negative lens which is located second from the object side, it is preferable to make an object-side surface a strong diverging surface.

In a case in which a value exceeds an upper limit value of conditional expression (19), the light-ray height in the first lens unit is susceptible to become high. In a case in which the value falls below a lower limit value of conditional expression (19), the astigmatism is susceptible to occur.

It is preferable that following conditional expression (19') be satisfied instead of conditional expression (19).

$$-0.8<fL/R12F_e<0.2 \tag{19'}$$

Moreover, it is more preferable that following conditional expression (19") be satisfied instead of conditional expression (19).

$$-0.6<fL/R12F_e<0.0 \tag{19''}$$

In the wide-angle optical system of the present embodiment, it is preferable that the first lens unit include a fourth lens component, a fifth lens component, and a sixth lens component, the fourth lens component be a lens component located nearest to the object in the first lens unit, the fifth lens component be a lens component located second from the object side in the first lens unit, the sixth lens component be a lens component located third from the object side in the first lens unit, the fourth lens component include a negative lens component, the fifth lens component include a lens component for which an absolute value of refractive power is smaller than an absolute value of a refractive power of the fourth lens component, the sixth lens component include a cemented lens, and following conditional expression (20) be satisfied:

$$-1.2<fL/R12F_a<0.2 \tag{20}$$

where,

$R12F_a$ denotes a radius of curvature of a surface on the object side of the sixth lens component, and

fL denotes the focal length of the wide-angle optical system at the first position.

As mentioned above, in an optical system of an endoscope, the surface located nearest to the object becomes a flat surface or a surface convex toward the object side. Therefore, in the negative lens which located third from the object side, it is preferable to make an object-side surface a strong diverging surface.

In a case in which a value exceeds an upper limit value of conditional expression (20), the light-ray height in the first lens unit is susceptible to become high. In a case in which the value falls below a lower limit value of conditional expression (20), the astigmatism is susceptible to occur.

It is preferable that following conditional expression (20') be satisfied instead of conditional expression (20).

$$-0.9<fL/R12F_a<0.0 \tag{20'}$$

Moreover, it is more preferable that following conditional expression (20") be satisfied instead of conditional expression (20).

$$-0.6<fL/R12F_a<-0.2 \tag{19''}$$

In the wide-angle optical system of the present embodiment, it is preferable that the first lens unit include a fourth lens component and a fifth lens component, the fourth lens component be a lens component located nearest to the object in the first lens unit, the fifth lens component be a lens component located second from the object side in the first lens unit, and following conditional expression (21) be satisfied:

$$-1.0<fL/fL12<0.4 \tag{21}$$

where,

fL12 denotes a focal length of the fifth lens component, and

fL denotes the focal length of the wide-angle optical system at the first position.

In a case in which a value exceeds an upper limit value of conditional expression (21), it is not possible to achieve much effect of size reduction of the fourth component. In a case in which the value falls below a lower limit value of conditional expression (21), it is not possible to achieve much effect of correction of the off-axis aberration.

It is preferable that following conditional expression (21') be satisfied instead of conditional expression (21).

$$-0.7<fL/fL12<0.2 \tag{21'}$$

Moreover, it is more preferable that following conditional expression (21") be satisfied instead of conditional expression (21).

$$-0.6<fL/fL12<0.16 \tag{21''}$$

It is preferable that the wide-angle optical system of the present embodiment include an image-side lens component, the image-side lens component, among the plurality of lens components, be a lens component located nearest to an image, and following conditional expression (22) be satisfied:

$$100\times|f_{fin}|<|R_{fin}| \tag{22}$$

where,

$f_{fin}$ denotes a focal length of an image-side lens component, and

$R_{fin}$ denotes a radius of curvature of a surface on the image side of the image-side lens component.

In an optical system, an optical element having a zero refractive power is disposed between an image-side lens component and an image plane in many cases. An optical element having zero refractive power is an optical filter or a prism, for example. In a case in which conditional expression (22) is satisfied, it becomes easier both of securing a space for disposing the optical element having a zero refractive power and favorable correction of ng achieve both of the astigmatism.

In conditional expression (5) and conditional expression (6), for the lens component located nearest to the image, the radius of curvature of the surface is regulated. In conditional expression (22), for the image-side lens component, the radius of curvature of the surface is regulated. The image-side lens component is a lens component located nearest to the image. Accordingly, conditional expression (22), practically, can be said to be a conditional expression regulating conditional expression (5) and conditional expression (6).

It is preferable that the wide-angle optical system of the present embodiment include the image-side lens component and an optical element having zero refractive power, wherein the image-side lens component, among the plurality of lens components, be a lens component located nearest to the image, the optical element be located on the image side of the image-side lens component, and the image-side lens component and the optical element be cemented.

In an optical system, an optical element having a zero refractive power is disposed between an image-side lens component and an image plane in many cases. An optical element having zero refractive power is an optical filter or a prism, for example. By cementing the image-side lens component and the optical element, it is possible to prevent degradation of an imaging performance due to decentering.

In the wide-angle optical system of the present embodiment, it is preferable that following conditional expression (23) be satisfied:

$$2\times y_{max}<fL\times\tan\,\omega_{max} \tag{23}$$

where,

$y_{max}$ denotes a maximum image height,

$\omega_{max}$ denotes an angle of view corresponding to the maximum image height, and

fL denotes the focal length of the wide-angle optical system at the first position.

The wide-angle optical system of the present embodiment is an optical system which has a high resolution and a small outer diameter, and an actuator necessary for the focal-position adjustment disposed therein. Accordingly, it is possible to use the wide-angle optical system of the present embodiment for an optical system of an endoscope.

For using the wide-angle optical system of the present embodiment for an optical system of an endoscope, it is preferable that an angle of view of not less than 100 degrees be secured, for instance. In an optical system having an angle of view of not less than 100 degrees, an occurrence of a distortion is acceptable. Accordingly, such optical system does not satisfy following expression (A). Expression (A) is a condition with no distortion.

$$Y_{max}=fL\times\tan\,\omega_{max} \tag{A}$$

Instead, the wide-angle optical system of the present embodiment satisfies conditional expression (23). By satisfying conditional expression (23), it is possible to make an outer diameter of an optical unit small while securing a wide angle of view. Accordingly, it is possible to use the wide-angle optical system of the present embodiment for an optical system of an endoscope.

In the wide-angle optical system of the present embodiment, it is preferable that following conditional expression (24) be satisfied:

$$ER2<4\times fL/F_{EX} \tag{24}$$

where,

ER2 denotes an effective radius of a surface nearest to the image of the second lens component,

$F_{EX}$ denotes an effective F-value at the first position, and

fL denotes the focal length of the wide-angle optical system at the first position.

Conditional expression (24) is a conditional expression related to the light-ray height. By satisfying conditional expression (24), it is possible to use the wide-angle optical system of the present embodiment for an optical system of an endoscope. The effective radius is determined by the height of an outermost light ray in a plane.

An image pickup apparatus of the present embodiment includes an optical system, and an image sensor which is disposed on an image plane, wherein the image sensor has an image pickup surface, and converts an image formed on the image pickup surface by the optical system to an electric signal, and the optical system is the abovementioned wide-angle optical system.

According to the image pickup apparatus of the present embodiment, even when an image sensor with a large number of pixels is used, it is possible to acquire a sharp image corresponding to the large number of pixels.

Embodiments and examples of a wide-angle optical system will be described below in detail by referring to the accompanying diagrams. However, the present disclosure is not restricted to the embodiments and the examples described below.

Lens cross-sectional views of each example will be described below.

FIG. **1**A, FIG. **2**A, FIG. **3**A, FIG. **4**A, FIG. **5**A, FIG. **6**A, FIG. **7**A, FIG. **8**A, FIG. **9**A, FIG. **10**A, FIG. **11**A, FIG. **12**A, FIG. **13**A, and FIG. **14**A are cross-sectional views at a far point.

FIG. **1**B, FIG. **2**B, FIG. **3**B, FIG. **4**B, FIG. **5**B, FIG. **6**B, FIG. **7**B, FIG. **8**B, FIG. **9**B, FIG. **10**B, FIG. **11**B, FIG. **12**B, FIG. **13**B, and FIG. **14**B are cross-sectional views at a near point.

A first lens unit is denoted by G**1**, a second lens unit is denoted by G**2**, a third lens unit is denoted by G**3**, an aperture stop is denoted by S, a filter is denoted by F, a cover glass is denoted by C, a prism is denoted by P, and an image plane (image pickup surface) is denoted by I.

Aberration diagrams of each example will be described below. Aberration diagrams are shown in order of aberration diagrams at a far point and aberration diagrams at a near point.

Aberration diagrams at a far point are as follow.

FIG. **15**A, FIG. **16**A, FIG. **17**A, FIG. **18**A, FIG. **19**A, FIG. **20**A, FIG. **21**A, FIG. **22**A, FIG. **23**A, FIG. **24**A, FIG. **25**A, FIG. **26**A, FIG. **27**A, and FIG. **28**A show a spherical aberration (SA).

FIG. **15**B, FIG. **16**B, FIG. **17**B, FIG. **18**B, FIG. **19**B, FIG. **20**B, FIG. **21**B, FIG. **22**B, FIG. **23**B, FIG. **24**B, FIG. **25**B, FIG. **26**B, FIG. **27**B, and FIG. **28**B show an astigmatism (AS).

FIG. **15**C, FIG. **16**C, FIG. **17**C, FIG. **18**C, FIG. **19**C, FIG. **20**C, FIG. **21**C, FIG. **22**C, FIG. **23**C, FIG. **24**C, FIG. **25**C, FIG. **26**C, FIG. **27**C, and FIG. **28**C show a chromatic aberration of magnification (CC).

FIG. **15**D, FIG. **16**D, FIG. **17**D, FIG. **18**D, FIG. **19**D, FIG. **20**D, FIG. **21**D, FIG. **22**D, FIG. **23**D, FIG. **24**D, FIG. **25**D, FIG. **26**D, FIG. **27**D, and FIG. **28**D show a distortion (DT).

Aberration diagrams at a near point are as follow.

FIG. **15**E, FIG. **16**E, FIG. **17**E, FIG. **18**E, FIG. **19**E, FIG. **20**E, FIG. **21**E, FIG. **22**E, FIG. **23**E, FIG. **24**E, FIG. **25**E, FIG. **26**E, FIG. **27**E, and FIG. **28**E show a spherical aberration (SA).

FIG. **15**F, FIG. **16**F, FIG. **17**F, FIG. **18**F, FIG. **19**F, FIG. **20**F, FIG. **21**F, FIG. **22**F, FIG. **23**F, FIG. **24**F, FIG. **25**F, FIG. **26**F, FIG. **27**F, and FIG. **28**F show an astigmatism (AS).

FIG. **15**G, FIG. **16**G, FIG. **17**G, FIG. **18**G, FIG. **19**G, FIG. **20**G, FIG. **21**G, FIG. **22**G, FIG. **23**G, FIG. **24**G, FIG. **25**G, FIG. **26**G, FIG. **27**G, and FIG. **28**G show a chromatic aberration of magnification (CC).

FIG. **15**H, FIG. **16**H, FIG. **17**H, FIG. **18**H, FIG. **19**H, FIG. **20**H, FIG. **21**H, FIG. **22**H, FIG. **23**H, FIG. **24**H, FIG. **25**H, FIG. **26**H, FIG. **27**H, and FIG. **28**H show a distortion (DT).

A wide-angle optical system of an example 1 includes in order from an object side, a first lens unit G**1** having a negative refractive power, a second lens unit G**2** having a positive refractive power, and a third lens unit G**3** having a positive refractive power.

The first lens unit G**1** includes a planoconcave negative lens L1, a biconcave negative lens L2, and a biconvex positive lens L3.

The second lens unit G**2** includes a positive meniscus lens L4 having a convex surface directed toward the object side.

The third lens unit G**3** includes a biconvex positive lens L5, a negative meniscus lens L6 having a convex surface directed toward an image side, a biconvex positive lens L7, a biconcave negative lens L8, a negative meniscus lens L9 having a convex surface directed toward the object side, a biconvex positive lens L10, a biconvex positive lens L11, and a negative meniscus lens L12 having a convex surface directed toward the image side.

The biconvex positive lens L5 and the negative meniscus lens L6 are cemented. The biconvex positive lens L11 and the negative meniscus lens L12 are cemented.

A filter F is disposed in the first lens unit G**1**. An aperture stop S is disposed between the second lens unit G**2** and the third lens unit G**3**. A cover glass C is disposed on an image side of the third lens unit G**3**.

In an adjustment of a focal position, the second lens unit G**2** is moved. At the time of adjustment from a far point to a near point, the second lens unit G**2** is moved toward the image side.

A wide-angle optical system of an example 2 includes in order from an object side, a first lens unit G**1** having a negative refractive power, a second lens unit G**2** having a positive refractive power, and a third lens unit G**3** having a positive refractive power.

The first lens unit G**1** includes a planoconcave negative lens L1, a biconcave negative lens L2, and a positive meniscus lens L3 having a convex surface directed toward the object side.

The second lens unit G**2** includes a positive meniscus lens L4 having a convex surface directed toward the object side.

The third lens unit G**3** includes a positive meniscus lens L5 having a convex surface directed toward the object side, a negative meniscus lens L6 having a convex surface directed toward the object side, a biconvex positive lens L7, a positive meniscus lens L8 having a convex surface directed toward an image side, a biconcave negative lens L9, a positive meniscus lens L10 having a convex surface directed toward the image side, and a biconvex positive lens L11.

The negative meniscus lens L6 and the biconvex positive lens L7 are cemented. The positive meniscus lens L8 and the biconcave negative lens L9 are cemented.

A filter F is disposed in the first lens unit G**1**. An aperture stop S is disposed between the second lens unit G**2** and the third lens unit G**3**. A cover glass C is disposed on an image side of the third lens unit G**3**.

In an adjustment of a focal position, the second lens unit G**2** is moved. At the time of adjustment from a far point to a near point, the second lens unit G**2** is moved toward the image side.

A wide-angle optical system of an example 3 includes in order from an object side, a first lens unit G**1** having a negative refractive power, a second lens unit G**2** having a positive refractive power, and a third lens unit G**3** having a positive refractive power.

The first lens unit G**1** includes a negative meniscus lens L1 having a convex surface directed toward the object side, a biconcave negative lens L2, and a positive meniscus lens L3 having a convex surface directed toward the object side.

The second lens unit G**2** includes a positive meniscus lens L4 having a convex surface directed toward the object side.

The third lens unit G**3** includes a positive meniscus lens L5 having a convex surface directed toward the object side, a biconcave negative lens L6, a biconvex positive lens L7, a positive meniscus lens L8 having a convex surface directed toward an image side, a biconcave negative lens L9, a biconvex positive lens L10, and a positive meniscus lens L11 having a convex surface directed toward the object side.

The biconcave negative lens L6 and the biconvex positive lens L7 are cemented. The positive meniscus lens L8 and the biconcave negative lens L9 are cemented.

A filter F is disposed in the first lens unit G**1**. An aperture stop S is disposed between the second lens unit G**2** and the third lens unit G**3**. A cover glass C is disposed on an image side of the third lens unit G**3**.

In an adjustment of a focal position, the second lens unit G**2** is moved. At the time of adjustment from a far point to a near point, the second lens unit G**2** is moved toward the image side.

A wide-angle optical system of an example 4 includes in order from an object side, a first lens unit G**1** having a negative refractive power, a second lens unit G**2** having a positive refractive power, and a third lens unit G**3** having a positive refractive power.

The first lens unit G**1** includes a negative meniscus lens L1 having a convex surface directed toward the object side, a biconcave negative lens L2, and a positive meniscus lens L3 having a convex surface directed toward the object side.

The second lens unit G**2** includes a positive meniscus lens L4 having a convex surface directed toward the object side.

The third lens unit G**3** includes a positive meniscus lens L5 having a convex surface directed toward the object side, a negative meniscus lens L6 having a convex surface directed toward the object side, a biconvex positive lens L7, a biconvex positive lens L8, a biconcave negative lens L9, a biconvex positive lens L10, and a positive meniscus lens L11 having a convex surface directed toward the object side.

The negative meniscus lens L6 and the biconvex positive lens L7 are cemented. The biconvex positive lens L8 and the biconcave negative lens L9 are cemented.

A filter F is disposed in the first lens unit G**1**. An aperture stop S is disposed between the second lens unit G**2** and the third lens unit G**3**. A cover glass C is disposed on an image side of the third lens unit G**3**.

In an adjustment of a focal position, the second lens unit G**2** is moved. At the time of adjustment from a far point to a near point, the second lens unit G**2** is moved toward the image side.

A wide-angle optical system of an example 5 includes in order from an object side, a first lens unit G**1** having a negative refractive power, a second lens unit G**2** having a positive refractive power, and a third lens unit G**3** having a positive refractive power.

The first lens unit G**1** includes a negative meniscus lens L1 having a convex surface directed toward the object side, a biconcave negative lens L2, and a positive meniscus lens L3 having a convex surface directed toward the object side.

The second lens unit G**2** includes a positive meniscus lens L4 having a convex surface directed toward the object side.

The third lens unit G**3** includes a positive meniscus lens L5 having a convex surface directed toward the object side, a biconvex positive lens L6, a negative meniscus lens L7 having a convex surface directed toward an image side, a biconvex positive lens L8, a biconcave negative lens L9, a positive meniscus lens L10 having a convex surface directed toward the image side, a biconvex positive lens L11, and a planoconvex positive lens L12.

The biconvex positive lens L6 and the negative meniscus lens L7 are cemented. The biconvex positive lens L8 and the biconcave negative lens L9 are cemented.

A filter F is disposed between the first lens unit G**1** and the second lens unit G**2**. An aperture stop S is disposed in the third lens unit G**3**. A cover glass C is disposed on an image side of the third lens unit G**3**. The planoconvex positive lens L12 and the cover glass C are cemented.

In an adjustment of a focal position, the second lens unit G**2** is moved. At the time of adjustment from a far point to a near point, the second lens unit G**2** is moved toward the image side.

A wide-angle optical system of an example 6 includes in order from an object side, a first lens unit G**1** having a negative refractive power, a second lens unit G**2** having a positive refractive power, and a third lens unit G**3** having a positive refractive power.

The first lens unit G**1** includes a negative meniscus lens L1 having a convex surface directed toward the object side, a negative meniscus lens L2 having a convex surface directed toward an image side, and a positive meniscus lens L3 having a convex surface directed toward the image side.

The second lens unit G**2** includes a positive meniscus lens L4 having a convex surface directed toward the object side.

The third lens unit G**3** includes a biconvex positive lens L5, a negative meniscus lens L6 having a convex surface directed toward the image side, a biconvex positive lens L7, a negative meniscus lens L8 having a convex surface directed toward the object side, a positive meniscus lens L9 having a convex surface directed toward the object side, a biconvex positive lens L10, a negative meniscus lens L11 having a convex surface directed toward the image side, a negative meniscus lens L12 having a convex surface directed toward the image side, a negative meniscus lens L13 having a convex surface directed toward the object side, and a planoconvex positive lens L14.

The biconvex positive lens L5 and the negative meniscus lens L6 are cemented. The negative meniscus lens L8 and the positive meniscus lens L9 are cemented. The biconvex positive lens L10 and the negative meniscus lens L11 are cemented.

A filter F is disposed in the first lens unit G**1**. An aperture stop S is disposed in the third lens unit G**3**. A cover glass C is disposed on an image side of the third lens unit G**3**. The planoconvex positive lens L14 and the cover glass C are cemented.

In an adjustment of a focal position, the second lens unit G**2** is moved. At the time of adjustment from a far point to a near point, the second lens unit G**2** is moved toward the image side.

A wide-angle optical system of an example 7 includes in order from an object side, a first lens unit G**1** having a negative refractive power, a second lens unit G**2** having a positive refractive power, and a third lens unit G**3** having a positive refractive power.

The first lens unit G**1** includes a planoconcave negative lens L1, a biconcave negative lens L2, and a positive meniscus lens L3 having a convex surface directed toward the object side. The biconcave negative lens L2 and the positive meniscus lens L3 are cemented.

The second lens unit G**2** includes a positive meniscus lens L4 having a convex surface directed toward the object side.

The third lens unit G**3** includes a negative meniscus lens L5 having a convex surface directed toward the object side, a biconvex positive lens L6, a negative meniscus lens L7 having a convex surface directed toward the object side, a biconvex positive lens L8, a biconcave negative lens L9, a biconvex positive lens L10, a biconvex positive lens L11, and a negative meniscus lens L12 having a convex surface directed toward the object side.

The negative meniscus lens L5 and the biconvex positive lens L6 are cemented. The negative meniscus lens L7 and the biconvex positive lens L8 are cemented. The biconcave negative lens L9 and the biconvex positive lens L10 are cemented.

A filter F is disposed in the first lens unit G**1**. An aperture stop S is disposed in the third lens unit G**3**. A cover glass C and a prism P are disposed on an image side of the third lens unit G**3**.

In an adjustment of a focal position, the second lens unit G**2** is moved. At the time of adjustment from a far point to a near point, the second lens unit G**2** is moved toward the image side.

A wide-angle optical system of an example 8 includes in order from an object side, a first lens unit G**1** having a negative refractive power, a second lens unit G**2** having a positive refractive power, and a third lens unit G**3** having a positive refractive power.

The first lens unit G**1** includes a planoconcave negative lens L1, a planoconvex positive lens L2, a biconcave negative lens L3, and a biconvex positive lens L4. The biconcave negative lens L3 and the biconvex positive lens L4 are cemented.

The second lens unit G**2** includes a positive meniscus lens L5 having a convex surface directed toward the object side.

The third lens unit G**3** includes a biconvex positive lens L6, a negative meniscus lens L7 having a convex surface directed toward an image side, a negative meniscus lens L8 having a convex surface directed toward the object side, a positive meniscus lens L9 having a convex surface directed toward the object side, a biconvex positive lens L10, a negative meniscus lens L11 having a convex surface directed toward the image side, and a planoconvex positive lens L12.

The biconvex positive lens L6 and the negative meniscus lens L7 are cemented. The negative meniscus lens L8 and the positive meniscus lens L9 are cemented. The biconvex positive lens L10 and the negative meniscus lens L11 are cemented.

An aperture stop S and a filter F are disposed in the third lens unit G3. A cover glass C is disposed on an image side of the third lens unit G3. The planoconvex positive lens L12 and the cover glass C are cemented.

In an adjustment of a focal-position, the second lens unit G2 is moved. At the time of adjustment from a far point to a near point, the second lens unit G2 is moved toward the image side.

A wide-angle optical system of an example 9 includes in order from an object side, a first lens unit G1 having a negative refractive power, a second lens unit G2 having a positive refractive power, and a third lens unit G3 having a positive refractive power.

The first lens unit G1 includes a planoconcave negative lens L1, a positive meniscus lens L2 having a convex surface directed toward an image side, a biconcave negative lens L3, and a biconvex positive lens L4. The biconcave negative lens L3 and the biconvex positive lens L4 are cemented.

The second lens unit G2 includes a positive meniscus lens L5 having a convex surface directed toward the object side.

The third lens unit G3 includes a biconvex positive lens L6, a biconcave negative lens L7, a negative meniscus lens L8 having a convex surface directed toward the object side, a positive meniscus lens L9 having a convex surface directed toward the object side, a biconvex positive lens L10, a negative meniscus lens L11 having a convex surface directed toward the image side, and a planoconvex positive lens L12.

The biconvex positive lens L6 and the biconcave negative lens L7 are cemented. The negative meniscus lens L8 and the positive meniscus lens L9 are cemented. The biconvex positive lens L10 and the negative meniscus lens L11 are cemented.

An aperture stop S and a filter F are disposed in the third lens unit G3. A cover glass C is disposed on an image side of the third lens unit G3. The planoconvex positive lens L12 and the cover glass C are cemented.

In an adjustment of a focal-position, the second lens unit G2 is moved. At the time of adjustment from a far point to a near point, the second lens unit G2 is moved toward the image side.

A wide-angle optical system of an example 10 includes in order from an object side, a first lens unit G1 having a negative refractive power, a second lens unit G2 having a positive refractive power, and a third lens unit G3 having a positive refractive power.

The first lens unit G1 includes a planoconcave negative lens L1, a biconcave negative lens L2, and a positive meniscus lens L3 having a convex surface directed toward the object side. The biconcave negative lens L2 and the positive meniscus lens L3 are cemented.

The second lens unit G2 includes a positive meniscus lens L4 having a convex surface directed toward the object side.

The third lens unit G3 includes a positive meniscus lens L5 having a convex surface directed toward the object side, a negative meniscus lens L6 having a convex surface directed toward the object side, a biconvex positive lens L7, a negative meniscus lens L8 having a convex surface directed toward the object side, a biconvex positive lens L9, and a planoconvex positive lens L10.

The negative meniscus lens L6 and the biconvex positive lens L7 are cemented. The negative meniscus lens L8 and the biconvex positive lens L9 are cemented.

A filter F is disposed in the first lens unit G1. An aperture stop S is disposed in the third lens unit G3. A cover glass C is disposed on an image side of the third lens unit G3. The planoconvex positive lens L10 and the cover glass C are cemented.

In an adjustment of a focal position, the second lens unit G2 is moved. At the time of adjustment from a far point to a near point, the second lens unit G2 is moved toward an image side.

A wide-angle optical system of an example 11 includes in order from an object side, a first lens unit G1 having a negative refractive power, a second lens unit G2 having a positive refractive power, and a third lens unit G3 having a positive refractive power.

The first lens unit G1 includes a planoconcave negative lens L1, a biconcave negative lens L2, and a biconvex positive lens L3. The biconcave negative lens L2 and the biconvex positive lens L3 are cemented.

The second lens unit G2 includes a positive meniscus lens L4 having a convex surface directed toward the object side.

The third lens unit G3 includes a negative meniscus lens L5 having a convex surface directed toward the object side, a biconvex positive lens L6, a negative meniscus lens L7 having a convex surface directed toward the object side, a biconvex positive lens L8, a negative meniscus lens L9 having a convex surface directed toward the object side, a biconvex positive lens L10, and a planoconvex positive lens L11.

The negative meniscus lens L5 and the biconvex positive lens L6 are cemented. The negative meniscus lens L7 and the biconvex positive lens L8 are cemented. The negative meniscus lens L9 and the biconvex positive lens L10 are cemented.

An aperture stop S and a filter F are disposed in the third lens unit G3. A cover glass C is disposed on an image side of the third lens unit G3. The planoconvex positive lens L11 and the cover glass C are cemented.

In an adjustment of a focal-position, the second lens unit G2 is moved. At the time of adjustment from a far point to a near point, the second lens unit G2 is moved toward an image side.

A wide-angle optical system of an example 12 includes in order from an object side, a first lens unit G1 having a negative refractive power, a second lens unit G2 having a positive refractive power, and a third lens unit G3 having a positive refractive power.

The first lens unit G1 includes a planoconcave negative lens L1.

The second lens unit G2 includes a positive meniscus lens L2 having a convex surface directed toward the object side.

The third lens unit G3 includes a biconvex positive lens L3, a negative meniscus lens L4 having a convex surface directed toward an image side, a biconvex positive lens L5, a biconcave negative lens L6, a biconvex positive lens L7, and a biconvex positive lens L8.

The biconvex positive lens L3 and the negative meniscus lens L4 are cemented. The biconvex positive lens L5, the biconcave negative lens L6, and the biconvex positive lens L7 are cemented.

A filter F is disposed between the first lens unit G1 and the second lens unit G2. An aperture stop S is disposed in the third lens unit G3. A prism P and a cover glass C are disposed on an image side of the third lens unit G3.

In an adjustment of a focal position, the second lens unit G**2** is moved. At the time of adjustment from a far point to a near point, the second lens unit G**2** is moved toward the image side.

A wide-angle optical system of an example 13 includes in order from an object side, a first lens unit G**1** having a negative refractive power, a second lens unit G**2** having a positive refractive power, and a third lens unit G**3** having a positive refractive power.

The first lens unit G**1** includes a planoconcave negative lens L1, a biconcave negative lens L2, and a biconvex positive lens L3. The biconcave negative lens L2 and the biconvex positive lens L3 are cemented.

The second lens unit G**2** includes a positive meniscus lens L4 having a convex surface directed toward the object side.

The third lens unit G**3** includes a biconvex positive lens L5, a biconvex positive lens **6**, a negative meniscus lens L7 having a convex surface directed toward an image side, and a planoconvex positive lens L8. The biconvex positive lens L6 and the negative meniscus lens L7 are cemented.

An aperture stop S is disposed between the second lens unit G**2** and the third lens unit G**3**. A filter F is disposed in the third lens unit G**3**. A cover glass C is disposed on an image side of the third lens unit G**3**. The planoconvex positive lens L8 and the cover glass C are cemented.

In an adjustment of a focal position, the second lens unit G**2** is moved. At the time of adjustment from a far point to a near point, the second lens unit G**2** is moved toward the image side.

A wide-angle optical system of an example 14 includes in order from an object side, a first lens unit G**1** having a negative refractive power, a second lens unit G**2** having a positive refractive power, and a third lens unit G**3** having a positive refractive power.

The first lens unit G**1** includes a planoconcave negative lens L1, a biconcave negative lens L2, and a biconvex positive lens L3. The biconcave negative lens L2 and the biconvex positive lens L3 are cemented.

The second lens unit G**2** includes a positive meniscus lens L4 having a convex surface directed toward the object side.

The third lens unit G**3** includes a planoconvex positive lens L5, a negative meniscus lens L6 having a convex surface directed toward the objet side, a planoconvex positive lens L7, a biconvex positive lens L8, a negative meniscus lens L9 having a convex surface directed toward an image side, and a planoconvex positive lens L10.

The negative meniscus lens L6 and the planoconvex positive lens L7 are cemented. The biconvex positive lens L8 and the negative meniscus lens L9 are cemented.

An aperture stop S and a filter F are disposed in the third lens unit G**3**. A cover glass C is disposed on an image side of the third lens unit G**3**. The planoconvex positive lens L10 and the cover glass C are cemented.

In an adjustment of a focal position, the second lens unit G**2** is moved. At the time of adjustment from a far point to a near point, the second lens unit G**2** is moved toward the image side.

Numerical data of each example described above is shown below. In Surface data, r denotes radius of curvature of each lens surface, d denotes a distance between respective lens surfaces, nd denotes a refractive index of each lens for a d-line, νd denotes an Abbe number for each lens and * denotes an aspherical surface. A stop is an aperture stop.

Moreover, in Various data, OBJ denotes an object distance, FL denotes a focal length of the entire system, MG denotes a magnification of the entire system, NAI denotes a numerical aperture, FNO. denotes an F number, FIY and FIM denote an image height, LTL denotes a lens total length of the optical system, and FB denotes a back focus.

The back focus is a unit which is expressed upon air conversion of a distance from a rearmost lens surface to a paraxial image surface. The lens total length is a distance from a frontmost lens surface to the rearmost lens surface plus back focus. Moreover, β1 denotes a magnification of the first lens unit, β2 denotes a magnification of the second lens unit, β3 denotes a magnification of the third lens unit.

Further, in Unit focal length, each of f1, f2 . . . is a focal length of each lens unit.

A shape of an aspherical surface is defined by the following expression where the direction of the optical axis is represented by z, the direction orthogonal to the optical axis is represented by y, a conical coefficient is represented by K, aspherical surface coefficients are represented by A4, A6, A8, A10, A12. . .

$$Z=(y^2/r)/[1+\{1-(1+k)\ (y/r)^2\}^{1/2}]+A4\ y^4+A6\ y^6+A8\ y^8+A10\ y^{10}+A12\ y^{12}+. . .$$

Further, in the aspherical surface coefficients, 'E -n' (where, n is an integral number) indicates '$10^{-n}$'. Moreover, these symbols are commonly used in the following numerical data for each example.

## Example 1

Unit mm

Surface data

| Surface no. | r | d | nd | νd | ER |
|---|---|---|---|---|---|
| Object plane | ∞ | 21.0000 | 1. | | |
| 1 | ∞ | 0.3700 | 1.88300 | 40.76 | 1.598 |
| 2 | 1.3365 | 0.7000 | 1. | | 1.054 |
| 3 | ∞ | 0.4000 | 1.51633 | 64.14 | 1.020 |
| 4 | ∞ | 0.2000 | 1. | | 0.970 |
| 5 | −2.4149 | 0.2932 | 1.88300 | 40.76 | 0.971 |
| 6 | 11.5245 | 0.0905 | 1. | | 1.030 |
| 7 | 9.8202 | 0.6960 | 1.78472 | 25.68 | 1.061 |
| 8 | −3.2386 | d8 | 1. | | 1.110 |
| 9 | 1.7471 | 0.5591 | 1.49700 | 81.54 | 1.033 |
| 10 | 1.8893 | d10 | 1. | | 0.904 |
| 11(Stop) | ∞ | 0.1000 | 1. | | 0.570 |
| 12 | 1.6617 | 0.8323 | 1.58913 | 61.14 | 0.648 |
| 13 | −1.3612 | 0.2948 | 1.83400 | 37.16 | 0.665 |
| 14 | −4.5054 | 0.0944 | 1. | | 0.706 |
| 15 | 2.3887 | 0.7740 | 1.58913 | 61.14 | 0.720 |
| 16 | −1.6464 | 0.0861 | 1. | | 0.676 |
| 17 | −1.3548 | 0.2847 | 1.88300 | 40.76 | 0.642 |
| 18 | 1.6199 | 0.0148 | 1. | | 0.669 |
| 19 | 1.5740 | 0.2830 | 1.69895 | 30.13 | 0.689 |
| 20 | 1.8348 | 0.0446 | 1. | | 0.712 |
| 21 | 1.9198 | 0.8306 | 1.51742 | 52.43 | 0.739 |
| 22 | −3.6617 | 0.0887 | 1. | | 0.828 |
| 23 | 9.6091 | 0.8470 | 1.51633 | 64.14 | 0.852 |
| 24 | −1.4071 | 0.2937 | 1.88300 | 40.76 | 0.873 |
| 25 | −4.5032 | 0.0856 | 1. | | 0.961 |
| 26 | ∞ | 1.5000 | 1.51633 | 64.14 | 0.988 |
| 27 | ∞ | 0.0700 | 1. | | 1.129 |
| Image plane | ∞ | 0. | | | |

Various data

| | Far Point | Near point |
|---|---|---|
| OBJ | 21.0000 | 2.9000 |
| FL | 1.08640 | 1.03636 |
| MG | −0.049360 | −0.266448 |
| NAI | 0.1264 | 0.1262 |
| FIY | 1.140 | 1.140 |

-continued

Various data

| | Far Point | Near point |
|---|---|---|
| LTL | 12.4438 | 12.4438 |
| FB | 0.01637 | −0.20614 |
| d8 | 0.36201 | 1.95324 |
| d10 | 2.24872 | 0.65748 |
| β1 | 0.06727 | 0.33940 |
| β2 | 1.12363 | 1.20217 |
| β3 | −0.65304 | −0.65304 |

Unit focal length

f1=−1.51854, f2=20.26060, f3=2.68873

## Example 2

Unit mm

Surface data

| Surface no. | r | d | nd | νd | ER |
|---|---|---|---|---|---|
| Object plane | ∞ | 21.0000 | 1. | | |
| 1 | ∞ | 0.3700 | 1.88300 | 40.76 | 1.881 |
| 2 | 1.8089 | 0.6000 | 1. | | 1.306 |
| 3 | ∞ | 0.4000 | 1.51633 | 64.14 | 1.293 |
| 4 | ∞ | 0.1633 | 1. | | 1.209 |
| 5 | −7.7140 | 0.2984 | 1.88300 | 40.76 | 1.185 |
| 6 | 3.9041 | 0.0965 | 1. | | 1.135 |
| 7 | 2.4546 | 0.8446 | 1.92286 | 18.90 | 1.157 |
| 8 | 3.1566 | d8 | 1. | | 1.013 |
| 9 | 2.2403 | 1.5268 | 1.49700 | 81.54 | 0.981 |
| 10 | 3.3915 | d10 | 1. | | 0.697 |
| 11(Stop) | ∞ | 0.0783 | 1. | | 0.460 |
| 12* | 4.0614 | 0.3192 | 1.88300 | 40.76 | 0.485 |
| 13* | 11.1597 | 0.0830 | 1. | | 0.526 |
| 14 | 2.0140 | 0.3000 | 1.88300 | 40.76 | 0.578 |
| 15 | 1.5060 | 0.8356 | 1.51742 | 52.43 | 0.586 |
| 16 | −1.5170 | 0.0934 | 1. | | 0.663 |
| 17 | −10.3264 | 1.2276 | 1.51633 | 64.14 | 0.654 |
| 18 | −1.3625 | 0.2968 | 1.84666 | 23.78 | 0.649 |
| 19 | 1.8989 | 0.2849 | 1. | | 0.704 |
| 20 | −48.9192 | 0.5397 | 1.72916 | 54.68 | 0.805 |
| 21 | −2.6727 | 0.0956 | 1. | | 0.941 |
| 22 | 3.6698 | 0.5463 | 1.88300 | 40.76 | 1.093 |
| 23 | −86.8018 | 0.3500 | 1. | | 1.101 |
| 24 | ∞ | 1.4000 | 1.51633 | 64.14 | 1.111 |
| 25 | ∞ | 0.0757 | 1. | | 1.137 |
| Image plane | ∞ | 0. | | | |

Aspherical surface data

12th surface

K=0.

A2=0.0000E+00, A4=2.2626E-02, A6=−1.5521E-01, A8=7.9970E-01,

A10=−1.6090E+00, A12=−1.8424E-01, A14=1.3225E+00,

A16=0.0000E+00, A18=0.0000E+00, A20=0.0000E+00
13th surface

K=0.

A2=0.0000E+00, A4=5.9775E-02, A6=−3.6261E-02, A8=2.2828E-01,

A10=−3.7908E-01, A12=7.3652E-02, A14=−4.9792E-01,

A16=0.0000E+00, A18=0.0000E+00, A20=0.0000E+00

Various data

| | Far Point | Near point |
|---|---|---|
| OBJ | 21.0000 | 2.9000 |
| FL | 0.95940 | 0.97543 |
| MG | −0.042789 | −0.227651 |
| FNO | 3.9659 | 3.8809 |
| FIY | 1.140 | 1.140 |
| LTL | 12.4974 | 12.4974 |
| FB | 0.03465 | −0.14635 |
| d8 | 0.37036 | 1.16143 |
| d10 | 1.30128 | 0.51021 |
| β1 | 0.04739 | 0.23415 |
| β2 | 1.11562 | 1.20142 |
| β3 | −0.80926 | −0.80926 |

Unit focal length
f1=−1.07556, f2=9.21973, f3=2.80485

## Example 3

Unit mm

Surface data

| Surface no. | r | d | nd | νd | ER |
|---|---|---|---|---|---|
| Object plane | ∞ | 17.0000 | 1. | | |
| 1 | 20.0000 | 0.3700 | 1.88300 | 40.76 | 2.170 |
| 2 | 1.8355 | 0.6000 | 1. | | 1.438 |
| 3 | ∞ | 0.4000 | 1.51633 | 64.14 | 1.482 |
| 4 | ∞ | 0.3651 | 1. | | 1.367 |
| 5 | −6.0073 | 0.7484 | 1.88300 | 40.76 | 1.260 |
| 6 | 3.8110 | 0.5388 | 1. | | 1.141 |
| 7 | 2.9102 | 0.4410 | 1.92286 | 18.90 | 1.179 |
| 8 | 4.0476 | d8 | 1. | | 1.118 |
| 9 | 2.4287 | 1.7001 | 1.49700 | 81.54 | 1.088 |
| 10 | 3.4681 | d10 | 1. | | 0.763 |
| 11(Stop) | ∞ | 0.0944 | 1. | | 0.501 |
| 12* | 1.7041 | 0.3825 | 1.88300 | 40.76 | 0.600 |
| 13* | 5.1778 | 0.2781 | 1. | | 0.590 |
| 14 | −29.8880 | 0.3000 | 1.88300 | 40.76 | 0.629 |
| 15 | 2.9929 | 0.6826 | 1.51633 | 64.14 | 0.668 |
| 16 | −1.6314 | 0.1268 | 1. | | 0.749 |
| 17 | −8.7698 | 1.5571 | 1.51633 | 64.14 | 0.757 |
| 18 | −1.4188 | 0.3403 | 1.84666 | 23.78 | 0.820 |
| 19 | 4.3711 | 0.6288 | 1. | | 0.933 |
| 20 | 264.1515 | 0.7659 | 1.72916 | 54.68 | 1.240 |
| 21 | −2.7702 | 0.1844 | 1. | | 1.362 |
| 22 | 2.3631 | 0.6206 | 1.88300 | 40.76 | 1.495 |
| 23 | 3.9331 | 0.4000 | 1. | | 1.392 |
| 24 | ∞ | 1.4000 | 1.51633 | 64.14 | 1.358 |
| 25 | ∞ | 0.0411 | 1. | | 1.147 |
| Image plane | ∞ | 0. | | | |

Image plane ∞ 0.
Aspherical surface data
12th surface
K=0.
A2=0.0000E+00, A4=5.2580E-02, A6=5.3691E-02, A8=−3.8939E-03,
A10=0.0000E+00 13th surface
K=0.
A2=0.0000E+00, A4=1.2458E-01, A6=7.6091E-02, A8=4.8603E-02,
A10=0.0000E+00

Various data

| | Far Point | Near point |
|---|---|---|
| OBJ | 17.0000 | 3.0000 |
| FL | 0.96374 | 0.99290 |

-continued

| Various data | | |
|---|---|---|
| | Far Point | Near point |
| MG | −0.051712 | −0.215244 |
| FNO | 3.8797 | 3.8945 |
| FIY | 1.140 | 1.140 |
| LTL | 14.5440 | 14.5440 |
| FB | −0.00878 | −0.17266 |
| d8 | 0.28712 | 1.03089 |
| d10 | 1.29110 | 0.54733 |
| β1 | 0.06071 | 0.23796 |
| β2 | 1.13728 | 1.20767 |
| β3 | −0.74900 | −0.74900 |

Unit focal length

f1=−1.14099, f2=10.56718, f3=4.20765

## Example 4

Unit mm

| Surface data | | | | | |
|---|---|---|---|---|---|
| Surface no. | r | d | nd | νd | ER |
| Object plane | ∞ | 17.0000 | 1. | | |
| 1 | 18.6062 | 0.3700 | 1.88300 | 40.76 | 1.550 |
| 2 | 1.1634 | 0.6000 | 1. | | 0.954 |
| 3 | ∞ | 0.4000 | 1.51633 | 64.14 | 0.921 |
| 4 | ∞ | 0.2106 | 1. | | 0.839 |
| 5 | −2.9012 | 0.2987 | 1.88300 | 40.76 | 0.816 |
| 6 | 6.6566 | 0.0969 | 1. | | 0.825 |
| 7 | 2.2651 | 0.4862 | 1.67270 | 32.10 | 0.857 |
| 8 | 7.9728 | d8 | 1. | | 0.830 |
| 9 | 2.1192 | 0.9855 | 1.49700 | 81.54 | 0.806 |
| 10 | 2.7662 | d10 | 1. | | 0.651 |
| 11(Stop) | ∞ | 0.0820 | 1. | | 0.510 |
| 12* | 1.5966 | 0.3119 | 1.88300 | 40.76 | 0.557 |
| 13* | 1.8942 | 0.0923 | 1. | | 0.547 |
| 14 | 1.2718 | 0.3000 | 1.88300 | 40.76 | 0.588 |
| 15 | 0.8534 | 1.2563 | 1.51742 | 52.43 | 0.549 |
| 16 | −2.5219 | 0.2499 | 1. | | 0.650 |
| 17 | 263.2306 | 0.8622 | 1.49700 | 81.54 | 0.650 |
| 18 | −1.3145 | 0.3172 | 1.92286 | 18.90 | 0.650 |
| 19 | 2.8013 | 0.1794 | 1. | | 0.733 |
| 20 | 17.9648 | 0.6025 | 1.78472 | 25.68 | 0.806 |
| 21 | −2.5539 | 0.0985 | 1. | | 0.937 |
| 22 | 4.4647 | 0.4767 | 1.78472 | 25.68 | 1.044 |
| 23 | 837.6148 | 0.3500 | 1. | | 1.056 |
| 24 | ∞ | 1.5000 | 1.51633 | 64.14 | 1.078 |
| 25 | ∞ | 0.0239 | 1. | | 1.140 |
| Image plane | ∞ | 0. | | | |

Aspherical surface data

12th surface

K=0.

A2=0.0000E+00, A4=5.4679E-02, A6=−7.3153E-02, A8=1.8821E-01,

A10=−2. 6187E-01

13th surface

K=0.

A2=0.0000E+00, A4=1.1151E-01, A6=−2.3505E-02, A8=4.5913E-02,

A10=−1.4874E-01

| Various data | | |
|---|---|---|
| | Far Point | Near point |
| OBJ | 17.0000 | 3.0000 |
| FL | 0.95516 | 0.95802 |
| MG | −0.052812 | −0.235620 |
| FNO | 3.9309 | 3.8269 |
| FIY | 1.140 | 1.140 |
| LTL | 11.7045 | 11.7045 |
| FB | −0.02656 | −0.20184 |
| d8 | 0.28665 | 1.04021 |
| d10 | 1.26710 | 0.51353 |
| β1 | 0.05086 | 0.21466 |
| β2 | 1.08934 | 1.15157 |
| β3 | −0.95317 | −0.95317 |

Unit focal length

f1=−0.93319, f2=12.10818, f3=2.86916

## Example 5

Unit mm

| Surface data | | | | | |
|---|---|---|---|---|---|
| Surface no. | r | d | nd | νd | ER |
| Object plane | ∞ | 17.0000 | 1. | | |
| 1 | 167.9781 | 0.3000 | 1.88300 | 40.76 | 1.564 |
| 2 | 1.6545 | 0.7012 | 1. | | 1.131 |
| 3 | −5.5183 | 0.3000 | 1.88300 | 40.76 | 1.082 |
| 4 | 3.1744 | 0.0871 | 1. | | 1.041 |
| 5 | 2.5804 | 0.7814 | 1.84666 | 23.78 | 1.066 |
| 6 | 6.9505 | 0.1577 | 1. | | 0.996 |
| 7 | ∞ | 0.4000 | 1.51633 | 64.14 | 0.988 |
| 8 | ∞ | d8 | 1. | | 0.965 |
| 9 | 1.8888 | 0.4616 | 1.49700 | 81.54 | 0.928 |
| 10 | 2.1977 | d10 | 1. | | 0.836 |
| 11* | 1.8361 | 0.5888 | 1.80625 | 40.91 | 0.610 |
| 12* | 6.3888 | 0.1529 | 1. | | 0.483 |
| 13(Stop) | ∞ | 0.1033 | 1. | | 0.434 |
| 14 | 7.9548 | 0.7137 | 1.49700 | 81.54 | 0.462 |
| 15 | −0.9463 | 0.2804 | 1.88300 | 50.15 | 0.534 |
| 16 | −1.4714 | 0.0811 | 1. | | 0.610 |
| 17 | 7.9058 | 1.2449 | 1.49700 | 81.54 | 0.624 |
| 18 | −1.8551 | 0.2802 | 1.84666 | 23.78 | 0.640 |
| 19 | 1.8960 | 0.2604 | 1. | | 0.682 |
| 20 | −28.2916 | 0.5750 | 1.69895 | 40.19 | 0.759 |
| 21 | −3.3461 | 0.0701 | 1. | | 0.916 |
| 22 | 6.3282 | 0.5457 | 1.69895 | 30.13 | 1.024 |
| 23 | −12.4763 | 0.3661 | 1. | | 1.083 |
| 24 | 5.0000 | 1.0000 | 1.88300 | 40.76 | 1.182 |
| 25 | ∞ | 0.6000 | 1.51633 | 64.14 | 1.162 |
| 26 | ∞ | 0.0441 | 1. | | 1.145 |
| Image plane | ∞ | 0. | | | |

Aspherical surface data

11th surface

K=0.4228

A2=0.0000E+00, A4=1.9118E-02, A6=0.0000E+00, A8=0.0000E+00,

A10=0.0000E+00

12th surface

K=0.

A2=0.0000E+00, A4=8.0725E-02, A6=0.0000E+00, A8=0.0000E+00,

A10=0.0000E+00

Various data

| | Far Point | Near point |
|---|---|---|
| OBJ | 17.0000 | 3.0000 |
| FL | 1.01557 | 1.01923 |
| MG | −0.055562 | −0.239423 |
| FNO | 3.9399 | 3.9046 |
| FIY | 1.140 | 1.140 |
| LTL | 11.7980 | 11.7980 |
| FB | −0.01230 | −0.19990 |
| d8 | 0.18900 | 1.30877 |
| d10 | 1.51315 | 0.39339 |
| β1 | 0.06224 | 0.25370 |
| β2 | 1.08568 | 1.14764 |
| β3 | −0.82231 | −0.82231 |

Unit focal length
f1=−1.15452, f2=18.07196, f3=3.62238

## Example 6

Unit mm

Surface data

| Surface no. | r | d | nd | νd | ER |
|---|---|---|---|---|---|
| Object plane | ∞ | 23.0000 | 1. | | |
| 1 | 23.3351 | 0.3000 | 1.88300 | 40.76 | 1.615 |
| 2 | 1.3180 | 1.0918 | 1. | | 1.065 |
| 3 | −2.3725 | 0.3000 | 1.72916 | 54.68 | 0.965 |
| 4 | −14.0022 | 0.0758 | 1. | | 0.981 |
| 5 | ∞ | 0.4000 | 1.51633 | 64.14 | 0.983 |
| 6 | ∞ | 0.1000 | 1. | | 0.985 |
| 7 | −7.2570 | 0.5313 | 1.84666 | 23.78 | 0.986 |
| 8 | −4.6300 | d8 | 1. | | 1.019 |
| 9 | 1.5542 | 0.4753 | 1.49700 | 81.61 | 0.973 |
| 10 | 1.7441 | d10 | 1. | | 0.867 |
| 11 | 6.3417 | 0.8343 | 1.69895 | 30.13 | 0.700 |
| 12 | −1.2695 | 0.2967 | 1.84666 | 23.78 | 0.632 |
| 13 | −8.2452 | 0.0892 | 1. | | 0.610 |
| 14(Stop) | ∞ | 0.0900 | 1. | | 0.544 |
| 15 | 3.3742 | 1.3677 | 1.84666 | 23.78 | 0.628 |
| 16 | −37.5413 | 0.0916 | 1. | | 0.687 |
| 17 | 3.4999 | 0.8220 | 1.92286 | 18.90 | 0.698 |
| 18 | 1.4223 | 0.3889 | 1.49700 | 81.61 | 0.663 |
| 19 | 1.9638 | 0.0578 | 1. | | 0.700 |
| 20 | 2.2850 | 1.0027 | 1.49700 | 81.61 | 0.718 |
| 21 | −1.2509 | 0.2904 | 1.84666 | 23.78 | 0.794 |
| 22 | −2.1469 | 0.0769 | 1. | | 0.887 |
| 23 | −2.2922 | 0.5036 | 1.80610 | 40.92 | 0.894 |
| 24 | −2.7798 | 0.0825 | 1. | | 1.007 |
| 25 | 2.0361 | 0.2532 | 1.72825 | 28.46 | 1.067 |
| 26 | 1.6933 | 0.7456 | 1. | | 1.011 |
| 27 | 5.5337 | 1.0000 | 1.88300 | 40.76 | 1.122 |
| 28 | ∞ | 0.6000 | 1.51633 | 64.14 | 1.131 |
| 29 | ∞ | 0.0451 | 1. | | 1.138 |
| Image plane | ∞ | 0. | | | |

Various data

| | Far Point | Near point |
|---|---|---|
| OBJ | 23.0000 | 3.5000 |
| FL | 1.01803 | 1.00996 |
| MG | −0.042133 | −0.217390 |
| FNO | 3.8210 | 3.7550 |
| FIY | 1.140 | 1.140 |
| LTL | 13.4982 | 13.4982 |
| FB | 0.00220 | −0.17446 |
| d8 | 0.26049 | 1.10362 |
| d10 | 1.32512 | 0.48199 |
| β1 | 0.04971 | 0.24508 |
| β2 | 1.15340 | 1.20715 |
| β3 | −0.73482 | −0.73482 |

Unit focal length
f1=−1.21606, f2=15.68585, f3=3.50719

## Example 7

Unit mm

Surface data

| Surface no. | r | d | nd | νd | ER |
|---|---|---|---|---|---|
| Object plane | ∞ | 13.0000 | 1. | | |
| 1 | ∞ | 0.2500 | 1.88300 | 40.76 | 1.404 |
| 2* | 0.9721 | 0.5998 | 1. | | 0.965 |
| 3 | ∞ | 0.4000 | 1.49400 | 75.01 | 0.945 |
| 4 | ∞ | 0.1025 | 1. | | 0.891 |
| 5 | −7.4090 | 0.3000 | 1.81600 | 46.62 | 0.881 |
| 6 | 1.0886 | 0.7980 | 1.80518 | 25.42 | 0.840 |
| 7 | 76.4205 | d7 | 1. | | 0.820 |
| 8* | 2.2208 | 0.4521 | 1.49700 | 81.54 | 0.786 |
| 9* | 2.9006 | d9 | 1. | | 0.722 |
| 10 | 6.3327 | 0.3000 | 1.83400 | 37.16 | 0.650 |
| 11 | 1.1384 | 1.1031 | 1.64769 | 33.79 | 0.614 |
| 12 | −9.1597 | 0.1000 | 1. | | 0.598 |
| 13(Stop) | ∞ | 0.1000 | 1. | | 0.590 |
| 14 | 2.4331 | 0.4109 | 1.81600 | 46.62 | 0.624 |
| 15 | 1.4835 | 0.6873 | 1.49700 | 81.54 | 0.615 |
| 16 | −1.5523 | 0.1000 | 1. | | 0.650 |
| 17 | −1.7693 | 0.3000 | 1.81600 | 46.62 | 0.643 |
| 18 | 4.9222 | 0.5112 | 1.49700 | 81.54 | 0.711 |
| 19 | −5.5507 | 0.1000 | 1. | | 0.795 |
| 20* | 5.0297 | 0.6920 | 1.49700 | 81.54 | 0.850 |
| 21* | −1.8981 | 0.1000 | 1. | | 0.907 |
| 22 | 16.7852 | 0.5780 | 1.83400 | 37.16 | 0.902 |
| 23 | 9.3753 | 0.4930 | 1. | | 0.882 |
| 24 | ∞ | 0.2000 | 1.51633 | 64.14 | 0.890 |
| 25 | ∞ | 0.1000 | 1. | | 0.892 |
| 26 | ∞ | 5.3000 | 1.63854 | 55.38 | 0.894 |
| 27 | ∞ | 0.0856 | 1. | | 0.950 |
| Image plane | ∞ | 0. | | | |

Aspherical surface data

2nd surface

K=−1.0000

A2=0.0000E+00, A4=−1.6360E-02, A6=4.6266E-02, A8=0.0000E+00,

A10=0.0000E+00

8th surface

K=0.

A2=0.0000E+00, A4=−5.2700E-02, A6=5.4101E-02, A8=4.5765E-03,

A10=0.0000E+00

9th surface

K=0.

A2=0. 0000E+00, A4=−4. 9134E-02, A6=6. 3791E-02, A8=0. 0000E+00,

A10=0.0000E+00

20th surface

K=0.

A2=0.0000E+00, A4=−5.9779E-03, A6=1.4095E-03, A8=0.0000E+00,

A10=0.0000E+00

21st surface

K=0.

A2=0.0000E+00, A4=2.2880E-02, A6=3.2241E-03, A8=0.0000E+00,

A10=0.0000E+00

Various data

| | Far Point | Near point |
|---|---|---|
| OBJ | 13.0000 | 2.4000 |
| FL | 0.80002 | 0.79259 |
| MG | −0.057538 | −0.240455 |
| FNO | 3.6407 | 3.5879 |
| FIM | 0.948 | 0.948 |
| LTL | 15.7036 | 15.7037 |
| FB | 0.03958 | −0.10492 |
| d7 | 0.30000 | 0.98746 |
| d9 | 1.24011 | 0.55265 |
| β1 | 0.06093 | 0.24500 |
| β2 | 1.11789 | 1.16191 |
| β3 | −0.84467 | −0.84469 |

Unit focal length

f1=–0.85974, f2=15.61736, f3=2.99266

## Example 8

Unit mm

Surface data

| Surface no. | r | d | nd | νd | ER |
|---|---|---|---|---|---|
| Object plane | ∞ | 11.5000 | 1. | | |
| 1 | ∞ | 0.2500 | 1.88300 | 40.76 | 1.436 |
| 2* | 0.8505 | 0.6529 | 1. | | 0.953 |
| 3 | 13.6043 | 0.5102 | 1.62004 | 36.26 | 0.919 |
| 4 | −4.6021 | 0.2426 | 1. | | 0.852 |
| 5 | −1.5808 | 0.2500 | 1.80400 | 46.57 | 0.809 |
| 6 | 3.0801 | 0.6314 | 1.80518 | 25.42 | 0.852 |
| 7 | −3.5286 | d7 | 1. | | 0.880 |
| 8* | 1.7682 | 0.5533 | 1.51633 | 64.14 | 0.833 |
| 9 | 2.1000 | d9 | 1. | | 0.727 |
| 10 | 2.0695 | 0.8114 | 1.63854 | 55.38 | 0.600 |
| 11 | −1.3646 | 0.2500 | 1.80100 | 34.97 | 0.507 |
| 12 | −26.3432 | 0.1000 | 1. | | 0.487 |
| 13 (Stop) | ∞ | 0.1000 | 1. | | 0.475 |
| 14 | 1.5941 | 0.8544 | 1.80100 | 34.97 | 0.526 |
| 15 | 0.7801 | 0.6500 | 1.49700 | 81.54 | 0.508 |
| 16* | 2.2277 | 0.2000 | 1. | | 0.600 |
| 17 | 1.4012 | 0.8500 | 1.49700 | 81.54 | 0.770 |
| 18 | −1.6518 | 0.3000 | 1.81600 | 46.62 | 0.785 |
| 19 | −6.6118 | 0.2000 | 1. | | 0.840 |
| 20 | ∞ | 0.4000 | 1.49400 | 75.01 | 0.870 |
| 21 | ∞ | 0.6001 | 1. | | 0.901 |
| 22 | 3.9388 | 0.5256 | 1.76182 | 26.52 | 0.987 |
| 23 | ∞ | 0.3000 | 1.51633 | 64.14 | 0.968 |
| 24 | ∞ | 0.0263 | 1. | | 0.952 |
| Image plane | ∞ | 0. | | | |

Aspherical surface data

2nd surface

K=–0.7649

A2=0.0000E+00, A4=–7.8745E-02, A6=2.3040E-02, A8=5.7998E-03,

A10=0.0000E+00

8th surface

K=–0.5166

A2=0.0000E+00, A4=–5.0786E-04, A6=9.9993E-03, A8=0.0000E+00,

A10=0.0000E+00

16th surface

K=0.

A2=0.0000E+00, A4=1.0123E-01, A6=–6.6182E-02, A8=9.6241E-02,

A10=0.0000E+00

Various data

| | Far Point | Near point |
|---|---|---|
| OBJ | 11.5000 | 2.0000 |
| FL | 0.77283 | 0.76709 |
| MG | −0.062553 | −0.269761 |
| FNO | 3.6083 | 3.5385 |
| FIM | 0.948 | 0.948 |
| LTL | 10.8109 | 10.8109 |
| FB | −0.02202 | −0.18060 |
| d7 | 0.29000 | 1.05123 |
| d9 | 1.26273 | 0.50150 |
| β1 | 0.07260 | 0.29872 |
| β2 | 1.14373 | 1.19879 |
| β3 | −0.75331 | −0.75331 |

Unit focal length

f1=–0.91119, f2=13.82488, f3=3.05955

## Example 9

Unit mm

Surface data

| Surface no. | r | d | nd | νd | ER |
|---|---|---|---|---|---|
| Object plane | ∞ | 12.5000 | 1. | | |
| 1 | ∞ | 0.2500 | 1.88300 | 40.76 | 1.290 |
| 2 * | 0.8666 | 0.5899 | 1. | | 0.874 |
| 3 | −67.8910 | 0.4204 | 1.62004 | 36.26 | 0.850 |
| 4 | −11.6480 | 0.2250 | 1. | | 0.805 |
| 5 | −1.9029 | 0.2500 | 1.80400 | 46.57 | 0.786 |
| 6 | 2.7315 | 0.6194 | 1.80518 | 25.42 | 0.830 |
| 7 | −3.0429 | d7 | 1. | | 0.860 |
| 8 * | 1.7618 | 0.4866 | 1.51633 | 64.14 | 0.805 |
| 9 | 2.1000 | d9 | 1. | | 0.719 |
| 10 | 1.8693 | 0.8282 | 1.63854 | 55.38 | 0.600 |
| 11 | −1.2660 | 0.2500 | 1.80100 | 34.97 | 0.496 |
| 12 | 255.5774 | 0.1000 | 1. | | 0.472 |
| 13 (Stop) | ∞ | 0.1000 | 1. | | 0.460 |
| 14 | 1.5979 | 0.8190 | 1.80100 | 34.97 | 0.508 |
| 15 | 0.7863 | 0.6500 | 1.49700 | 81.54 | 0.496 |
| 16* | 2.2032 | 0.2000 | 1. | | 0.600 |
| 17 | 1.4729 | 0.8500 | 1.49700 | 81.54 | 0.747 |
| 18 | −2.4872 | 0.3000 | 1.81600 | 46.62 | 0.783 |
| 19 | −9.6848 | 0.2000 | 1. | | 0.828 |
| 20 | ∞ | 0.4000 | 1.49400 | 75.01 | 0.860 |
| 21 | ∞ | 0.6000 | 1. | | 0.897 |
| 22 | 3.1860 | 0.5610 | 1.76182 | 26.52 | 1.001 |
| 23 | ∞ | 0.3000 | 1.51633 | 64.14 | 0.975 |
| 24 | ∞ | 0.0259 | 1. | | 0.951 |
| Image plane | ∞ | 0. | | | |

Aspherical surface data

2nd surface

K=–0.4408

A2=0.0000E+00, A4=–1.1358E-01, A6=1.3043E-02, A8=–2.8998E-02,

A10=0.0000E+00 8th surface

K=0.2651

A2=0.0000E+00, A4=–1.5431E-02, A6=6.8384E-03, A8=0.0000E+00,

A10=0.0000E+00

16th surface

K=0.

A2=0.0000E+00, A4=1.2142E-01, A6=0.0000E+00, A8=0.0000E+00,

A10=0.0000E+00

| Various data | | |
|---|---|---|
| | Far Point | Near point |
| OBJ | 12.5000 | 2.1000 |
| FL | 0.80064 | 0.79640 |
| MG | −0.059913 | −0.269809 |
| FNO | 3.6030 | 3.5550 |
| FIM | 0.948 | 0.948 |
| LTL | 10.5879 | 10.5879 |
| FB | −0.02210 | −0.18901 |
| d7 | 0.29400 | 1.08080 |
| d9 | 1.26851 | 0.48171 |
| β1 | 0.07161 | 0.30780 |
| β2 | 1.16057 | 1.21589 |
| β3 | −0.72092 | −0.72092 |

Unit focal length

f1=−0.97051, f2=14.22153, f3=3.39668

## Example 10

Unit mm

| Surface data | | | | | |
|---|---|---|---|---|---|
| Surface no. | r | d | nd | νd | ER |
| Object plane | ∞ | 12.5000 | 1. | | |
| 1 | ∞ | 0.2500 | 1.88300 | 40.76 | 1.337 |
| 2* | 0.8692 | 0.5880 | 1. | | 0.900 |
| 3 | ∞ | 0.4000 | 1.49400 | 75.01 | 0.887 |
| 4 | ∞ | 0.0878 | 1. | | 0.848 |
| 5 | −9.0618 | 0.2500 | 1.81600 | 46.62 | 0.841 |
| 6 | 1.0427 | 0.7558 | 1.80518 | 25.42 | 0.815 |
| 7 | 17.0221 | d7 | 1. | | 0.801 |
| 8 * | 3.0758 | 0.4338 | 1.80610 | 40.92 | 0.798 |
| 9 | 3.6580 | d9 | 1. | | 0.740 |
| 10* | 2.1247 | 0.6051 | 1.72916 | 54.68 | 0.650 |
| 11* | 9.8770 | 0.1000 | 1. | | 0.523 |
| 12 (Stop) | ∞ | 0.1000 | 1. | | 0.505 |
| 13 | 2.4630 | 0.3572 | 1.74951 | 35.33 | 0.520 |
| 14 | 0.9957 | 1.5342 | 1.49700 | 81.54 | 0.517 |
| 15 | −4.3095 | 0.4000 | 1. | | 0.650 |
| 16 | 3.5884 | 0.3000 | 1.83400 | 37.16 | 0.735 |
| 17 | 1.5227 | 0.5851 | 1.49700 | 81.54 | 0.731 |
| 18* | −405.9130 | 0.6000 | 1. | | 0.777 |
| 19 | 3.5202 | 0.6000 | 1.53172 | 48.84 | 0.901 |
| 20 | ∞ | 2.4000 | 1.51633 | 64.14 | 0.910 |
| 21 | ∞ | 0.0260 | 1. | | 0.950 |
| Image plane | ∞ | 0. | | | |

Aspherical surface data

2nd surface

K=−0 0.9776

A2=0.0000E+00, A4=−8.8118E-03, A6=6.8995E-02, A8=0.0000E+00,

A10=0.0000E+00 8th surface

K=0.

A2=0.0000E+00, A4=−9.1674E-04, A6=3.1219E-02, A8=−8.5050E-03,

A10=0.0000E+00

10th surface

K=0.

A2=0.0000E+00, A4=−1.0574E-02, A6=−6.0806E-02, A8=0.0000E+00,

A10=0.0000E+00

11th surface

K=0.

A2=0.0000E+00, A4=2.6851E-03, A6=−6.5815E-02, A8=0.0000E+00,

A10=0.0000E+00

18th surface

K=0.

A2=0.0000E+00, A4=9.0488E-03, A6=−1.1887E-02, A8=0.0000E+00,

A10=0.0000E+00

| Various data | | |
|---|---|---|
| | Far Point | Near point |
| OBJ | 12.5000 | 2.1000 |
| FL | 0.79078 | 0.78170 |
| MG | −0.059423 | −0.269569 |
| FNO | 3.6685 | 3.5909 |
| FIM | 0.948 | 0.948 |
| LTL | 11.9080 | 11.9080 |
| FB | −0.02102 | −0.18476 |
| d7 | 0.23000 | 1.06652 |
| d9 | 1.30502 | 0.46850 |
| β1 | 0.05531 | 0.24046 |
| β2 | 1.07157 | 1.11807 |
| β3 | −1.00267 | −1.00267 |

Unit focal length

f1=−0.74700, f2=17.99209, f3=2.73069

## Example 11

Unit mm

| Surface data | | | | | |
|---|---|---|---|---|---|
| Surface no. | r | d | nd | νd | ER |
| Object plane | ∞ | 10.0000 | 1. | | |
| 1 | ∞ | 0.2500 | 1.88300 | 40.76 | 1.380 |
| 2* | 1.0031 | 0.9611 | 1. | | 0.964 |
| 3 | −3.9828 | 0.2500 | 1.81600 | 46.62 | 0.840 |
| 4 | 1.2000 | 0.7325 | 1.69895 | 30.13 | 0.803 |
| 5 | −11.8723 | d5 | 1. | | 0.801 |
| 6* | 1.7685 | 0.4535 | 1.49700 | 81.54 | 0.781 |
| 7* | 2.1000 | d7 | 1. | | 0.710 |
| 8 | 3.0533 | 0.3263 | 1.80400 | 46.58 | 0.650 |
| 9 | 1.0971 | 0.5783 | 1.67003 | 47.23 | 0.576 |
| 10 | −10.8438 | 0.1000 | 1. | | 0.544 |
| 12 (Stop) | ∞ | 0.1000 | 1. | | 0.525 |
| 12 | 3.6361 | 1.0893 | 1.83400 | 37.16 | 0.557 |
| 13 | 3.2493 | 0.4833 | 1.49700 | 81.54 | 0.604 |
| 14 | −7.5585 | 0.3269 | 1. | | 0.650 |
| 15 | 7.6519 | 0.3000 | 1.80518 | 25.42 | 0.709 |
| 16 | 1.5170 | 0.7129 | 1.49700 | 81.54 | 0.727 |
| 17* | −2.4421 | 0.1000 | 1. | | 0.795 |
| 18 | ∞ | 0.4000 | 1.49400 | 75.01 | 0.816 |
| 19 | ∞ | 0.6000 | 1. | | 0.840 |
| 20 | 6.8695 | 0.6732 | 1.49700 | 81.54 | 0.901 |
| 21 | ∞ | 2.4000 | 1.51633 | 64.14 | 0.911 |
| 22 | ∞ | 0.0265 | 1. | | 0.951 |
| Image plane | ∞ | 0. | | | |

Image plane ∞ 0.

Aspherical surface data

2nd surface

K=−1 0.9630

A2=0.0000E+00, A4=8.3944E-02, A6=−1.6945E-03, A8=0.0000E+00,

A10=0.0000E+00 6th surface

K=0.

A2=0.0000E+00, A4=−3.6151E-02, A6=1.9453E-02, A8=−5.8053E-03,

A10=0.0000E+00

7th surface

K=0.

A2=0.0000E+00, A4=−2.3622E-02, A6=0.0000E+00, A8=0.0000E+00,

A10=0.0000E+00

17th surface

K=0.

A2=0.0000E+00, A4=1.2915E-02, A6=−8.6587E-03, A8=0.0000E+00,

A10=0.0000E+00

Various data

| | Far Point | Near point |
|---|---|---|
| OBJ | 10.0000 | 2.0000 |
| FL | 0.77489 | 0.77102 |
| MG | −0.071294 | −0.269683 |
| FNO | 3.6407 | 3.5703 |
| FIM | 0.948 | 0.948 |
| LTL | 12.4265 | 12.4265 |
| FB | −0.02879 | −0.18148 |
| d5 | 0.25000 | 1.03523 |
| d7 | 1.31256 | 0.52733 |
| β1 | 0.06956 | 0.25131 |
| β2 | 1.07800 | 1.12865 |
| β3 | −0.95078 | −0.95078 |

Unit focal length

f1=−0.76944, f2=15.50141, f3=2.75593

## Example 12

Unit mm

Surface data

| Surface no. | r | d | nd | νd | ER |
|---|---|---|---|---|---|
| Object plane | ∞ | 15.0000 | 1. | | |
| 1 | ∞ | 0.2500 | 1.88300 | 40.76 | 1.270 |
| 2* | 0.7856 | 0.6500 | 1. | | 0.838 |
| 3 | ∞ | 0.4000 | 1.49400 | 75.01 | 0.824 |
| 4 | ∞ | d4 | 1. | | 0.800 |
| 5* | 1.9309 | 0.4597 | 1.49700 | 81.54 | 0.766 |
| 6 | 2.8631 | d6 | 1. | | 0.685 |
| 7 | 8.2193 | 0.5563 | 1.72825 | 28.46 | 0.492 |
| 8 | −0.8058 | 0.3000 | 1.81600 | 46.62 | 0.453 |
| 9 | −2.4732 | 0.1000 | 1. | | 0.430 |
| 10 (Stop) | ∞ | 0.6013 | 1. | | 0.395 |
| 11 | 9.1375 | 0.4871 | 1.49700 | 81.54 | 0.517 |
| 12 | −2.2107 | 0.2570 | 1.80518 | 25.42 | 0.562 |
| 13 | 1.6710 | 0.6818 | 1.49700 | 81.54 | 0.623 |
| 14 | −1.7198 | 0.1000 | 1. | | 0.728 |
| 15* | 2.9755 | 0.5709 | 1.49700 | 81.54 | 0.800 |
| 16 | −5.8213 | 0.6000 | 1. | | 0.818 |
| 17 | ∞ | 3.2000 | 1.88300 | 40.76 | 0.816 |
| 18 | ∞ | 0.3000 | 1.51633 | 64.14 | 0.812 |
| 19 | ∞ | 0.0263 | 1. | | 0.812 |
| Image plane | ∞ | 0. | | | |

Aspherical surface data

2nd surface

K=−1.0000

A2=0.0000E+00, A4=3.5380E-02, A6=2.5784E-02, A8=7.1050E-02,

A10=0.0000E+00

5th surface

K=0.

A2=0.0000E+00, A4=−1.5830E-02, A6=4.2282E-02, A8=1.6255E-02,

A10=0.0000E+00

15th surface

K=0.

A2=0.0000E+00, A4=2.1314E-03, A6=1.0242E-02, A8=0.0000E+00,

A10=0.0000E+00

Various data

| | Far Point | Near point |
|---|---|---|
| OBJ | 15.0000 | 1.7300 |
| FL | 0.70373 | 0.69457 |
| MG | −0.044525 | −0.275741 |
| FNO | 3.6056 | 3.5439 |
| FIM | 0.812 | 0.812 |
| LTL | 11.0387 | 11.0387 |
| FB | −0.00508 | −0.16527 |
| d4 | 0.26500 | 1.03032 |
| d6 | 1.23330 | 0.46798 |
| β1 | 0.05553 | 0.32325 |
| β2 | 1.16820 | 1.24284 |
| β3 | −0.68635 | −0.68635 |

Unit focal length

f1=−0.88975, f2=10.25404, f3=2.38964

## Example 13

Unit mm

Surface data

| Surface no. | r | d | nd | νd | ER |
|---|---|---|---|---|---|
| Object plane | ∞ | 12.0000 | 1. | | |
| 1 | ∞ | 0.2500 | 1.88300 | 40.76 | 0.959 |
| 2* | 0.5867 | 0.7292 | 1. | | 0.604 |
| 3 | −2.9628 | 0.2500 | 1.77250 | 49.60 | 0.580 |
| 4 | 1.8141 | 0.6400 | 1.84666 | 23.78 | 0.598 |
| 5 | −3.6936 | d5 | 1. | | 0.611 |
| 6 | 1.4089 | 0.5984 | 1.65160 | 58.55 | 0.568 |
| 7 | 1.5806 | d7 | 1. | | 0.446 |
| 8 (Stop) | ∞ | 0.1000 | 1. | | 0.320 |
| 9 | 3.0016 | 0.3300 | 1.49700 | 81.54 | 0.363 |
| 10 | −2.8548 | 0.2000 | 1. | | 0.415 |
| 11 | 3.2270 | 0.5193 | 1.49700 | 81.54 | 0.469 |
| 12 | −0.9500 | 0.5877 | 1.84666 | 23.78 | 0.498 |
| 13 | −1.9860 | 0.2000 | 1. | | 0.611 |
| 14 | ∞ | 0.4000 | 1.51633 | 64.14 | 0.629 |
| 15 | ∞ | 1.8314 | 1. | | 0.645 |
| 16 | 1.4990 | 0.4755 | 1.65160 | 58.55 | 0.769 |
| 17 | ∞ | 0.3000 | 1.51633 | 64.14 | 0.719 |
| 18 | ∞ | 0.0256 | 1. | | 0.656 |
| Image plane | ∞ | 0. | | | |

Aspherical surface data

2nd surface

K=−3 0.9151

A2=0.0000E+00, A4=1.8116E+00, A6=−3.8819E+00, A8=7.7408E+00,

A10=−6.1502E+00, A12=−1.6103E-08, A14=0.0000E+00,

A16=0.0000E+00, A18=0.0000E+00, A20=0.0000E+00

| Various data | | |
|---|---|---|
| | Far Point | Near point |
| OBJ | 12.0000 | 2.3000 |
| FL | 0.57445 | 0.58774 |
| MG | −0.045069 | −0.193515 |
| FNO | 3.7639 | 3.8219 |
| FIM | 0.644 | 0.644 |
| LTL | 8.5877 | 8.5877 |
| FB | −0.00025 | −0.08809 |
| d5 | 0.31000 | 0.75760 |
| d7 | 0.84053 | 0.39293 |
| β1 | 0.06232 | 0.25629 |
| β2 | 1.21026 | 1.26367 |
| β3 | −0.59752 | −0.59752 |

Unit focal length

f1=−0.79876, f2=8.38077, f3=3.42474

## Example 14

Unit mm

| Surface data | | | | | |
|---|---|---|---|---|---|
| Surface no. | r | d | nd | νd | ER |
| Object plane | ∞ | 12.0000 | 1. | | |
| 1 | ∞ | 0.3000 | 1.88300 | 40.76 | 0.956 |
| 2* | 0.6059 | 0.5726 | 1. | | 0.590 |
| 3 | −2.2791 | 0.3000 | 1.77250 | 49.60 | 0.568 |
| 4 | 2.2000 | 0.6000 | 1.84666 | 23.78 | 0.588 |
| 5 | −5.1712 | d5 | 1. | | 0.611 |
| 6* | 1.1177 | 0.5146 | 1.51633 | 64.14 | 0.582 |
| 7* | 1.2614 | d7 | 1. | | 0.492 |
| 8 | 2.4878 | 0.3800 | 1.72916 | 54.68 | 0.408 |
| 9 | ∞ | 0.1000 | 1. | | 0.378 |
| 10 (Stop) | ∞ | 0.1000 | 1. | | 0.370 |
| 11 | 1.7000 | 0.2500 | 1.80518 | 25.42 | 0.385 |
| 12 | 1.0712 | 0.5000 | 1.49700 | 81.54 | 0.381 |
| 13 | ∞ | 0.2000 | 1. | | 0.408 |
| 14 | 1.4815 | 0.7000 | 1.49700 | 81.54 | 0.456 |
| 15 | −0.9675 | 0.4036 | 1.88300 | 40.76 | 0.458 |
| 16 | −9.2037 | 0.2000 | 1. | | 0.515 |
| 17 | ∞ | 0.4000 | 1.49400 | 75.01 | 0.550 |
| 18 | ∞ | 0.7801 | 1. | | 0.593 |
| 19 | 1.6195 | 0.6259 | 1.69680 | 55.53 | 0.749 |
| 20 | ∞ | 0.3000 | 1.51633 | 64.14 | 0.695 |
| 21 | ∞ | 0.0264 | 1. | | 0.654 |
| Image plane | ∞ | 0. | | | |

2nd surface

K=−3.9794

A2=0.0000E+00, A4=1.7134E+00, A6=−3.7300E+00, A8=7.5080E+00,

A10=−5.6418E+OO, A12=−1.6099E-08, A14=0.0000E+00,

A16=0.0000E+00, A18=0.0000E+00, A20=0.0000E+00

6th surface

K=0.

A2=0.0000E+00, A4=−1.2803E-01, A6=0.0000E+00, A8=0.0000E+00,

A10=0.0000E+00

7th surface

K=0.

A2=0.0000E+00, A4=−1.0352E-01, A6=0.0000E+00, A8=0.0000E+00,

A10=0.0000E+00

| Various data | | |
|---|---|---|
| | Far Point | Near point |
| OBJ | 12.0000 | 2.3000 |
| FL | 0.59329 | 0.60659 |
| MG | −0.046655 | −0.201619 |
| FNO | 3.6591 | 3.6799 |
| FIM | 0.644 | 0.644 |
| LTL | 8.4232 | 8.4232 |
| FB | −0.00123 | −0.09585 |
| d5 | 0.30000 | 0.73415 |
| d7 | 0.87000 | 0.43585 |
| β1 | 0.05072 | 0.20971 |
| β2 | 1.12026 | 1.17095 |
| β3 | −0.82104 | −0.82104 |

Unit focal length

f1=−0.64900, f2=8.56357, f3=3.24456

Next, values of conditional expressions in each example are given below. ‘-’ (hyphen) indicates that there is no corresponding arrangement.

| | Example1 | Example2 | Example3 |
|---|---|---|---|
| (1) f3L12/fL | 1.294826951 | 1.804565353 | 2.308091394 |
| (2) fL/R31F | 0.65378829 | 0.23622396 | 0.56554193 |
| (3)fL × $\Sigma P_{SNi}$ | −0.4785357 | −0.4654942 | −0.3424523 |
| (5) $(R_{3R1} + R_{3R2})/(R_{3R1} - R_{3R2})$ | — | — | — |
| (6) $('R_{3R1} + 'R_{3R2})/('R_{3R1} - 'R_{3R2})$ | −0.3120846 | −0.918874 | −4.0103185 |
| (7) $fL/r_{SNr}$ | −0.7720844 | −0.7041468 | −0.6792642 |
| (8) $\nu_{31P} - \nu_{32P}$ | 0 | −11.67 | −23.38 |
| (9) $\nu_{33P} - (\nu_{31P} + \nu_{32P})/2$ | −31.01 | 17.545 | 11.69 |
| (10) $\nu_{31N} - \nu_{32N}$ | −3.6 | 16.98 | 16.98 |
| (11) (R21F + R21R)/(R21F − R21R) | −25.572433 | −4.8921126 | −5.673273 |
| (12) D21/fL | 0.51463549 | 1.5914113 | 1.764065 |
| (13) β2F | 1.12363 | 1.11562 | 1.13728 |
| (14) β2N/β2F | 1.06989845 | 1.07690791 | 1.06189329 |
| (15) $(1 - \beta 2F^2) \times \beta 3F^2$ | 0.17145198 | 0.19795146 | 0.21976094 |

-continued

| | | | |
|---|---|---|---|
| (16) $(1 - \beta2N^2) \times \beta3N^2$ | 0.29074171 | 0.35883399 | 0.34339165 |
| (17) $fL/R12F_a$ | −0.4498737 | −0.1243713 | −0.1604281 |
| (18) $fL/R12F_b$ | — | — | — |
| (19) $fL/R12F_c$ | −0.4498737 | −0.1243713 | −0.1604281 |
| (20) $fL/R12F_d$ | — | — | — |
| (21) $fL/FL12$ | −0.4852166 | −0.3307478 | −0.3779965 |
| (22) $\lvert R_{fin}\rvert/\lvert f_{fin}\rvert$ | 0.012346397 | 21.70696209 | 0.695422317 |
| (23) $fL \times \tan\omega_{max}$ | 6.28466714 | 7.38281509 | 5.57185721 |
| $2y_{max}$ | 2.28 | 2.28 | 2.28 |
| (24) ER2 | 0.676 | 0.663 | 0.749 |
| $4 \times fL/F_{EX}$ | 1.09848332 | 0.96373682 | 0.99482839 |

| | Example4 | Example5 | Example6 |
|---|---|---|---|
| (1) $f3L12/fL$ | 2.06321454 | 2.049095582 | 2.841763013 |
| (2) $fL/R31F$ | 0.59824627 | 0.55311258 | 0.16052951 |
| (3) $fL \times \Sigma EP_{SNi}$ | −0.7186162 | −0.6056761 | −0.7078323 |
| (5) $(R_{3R1} + R_{3R2})/(R_{3R1} - R_{3R2})$ | — | — | −1.0000011 |
| (6) $('R_{3R1} + 'R_{3R2})/('R_{3R1} - 'R_{3R2})$ | −1.0107176 | −1.0000001 | — |
| (7) $fL/r_{SNr}$ | −0.7266337 | −0.5474476 | −0.813838 |
| (8) $\nu_{31P} - \nu_{32P}$ | −11.67 | −40.63 | 6.35 |
| (9) $\nu_{33P} - (\nu_{31P} + \nu_{32P})/2$ | 34.945 | 20.315 | 54.655 |
| (10) $\nu_{31N} - \nu_{32N}$ | 21.86 | 26.37 | 4.88 |
| (11) $(R21F + R21R)/(R21F - R21R)$ | −7.5508501 | −13.2292 | −17.368615 |
| (12) $D21/fL$ | 1.03176431 | 0.45452308 | 0.46688212 |
| (13) $\beta2F$ | 1.08934 | 1.08568 | 1.1534 |
| (14) $\beta2N/\beta2F$ | 1.05712633 | 1.05707022 | 1.04660135 |
| (15) $(1 - \beta2F^2) \times \beta3F^2$ | 0.17792027 | 0.14694767 | 0.24273424 |
| (16) $(1 - \beta2N^2) \times \beta3N^2$ | 0.31084157 | 0.26073606 | 0.33596788 |
| (17) $fL/R12F_a$ | −0.3292293 | −0.1840368 | −0.4290959 |
| (18) $fL/R12F_b$ | — | — | — |
| (19) $fL/R12F_c$ | −0.3292293 | −0.1840368 | −0.4290959 |
| (20) $fL/R12F_d$ | — | — | — |
| (21) $fL/FL12$ | −0.4235367 | −0.4522086 | −0.2570458 |
| (22) $\lvert R_{fin}\rvert/\lvert f_{fin}\rvert$ | 146.472004 | 17660044.0 | 15956852.5 |
| (23) $fL \times \tan\omega_{max}$ | 5.542921362 | 2.74763805 | 4.27016993 |
| $2y_{max}$ | 2.28 | 2.28 | 2.28 |
| (24) ER2 | 0.65 | 0.610 | 0.687 |
| $4 \times fL/F_{EX}$ | 0.96676113 | 1.02842532 | 1.06183051 |

| | Example7 | Example8 | Example9 |
|---|---|---|---|
| (1) $f3L12/fL$ | 2.82442939 | 3.49882898 | 3.46073141 |
| (2) $fL/R31F$ | 0.12633158 | 0.37343803 | 0.42831006 |
| (3) $fL \times \Sigma EP_{SNi}$ | −0.3548088 | −0.5424258 | −0.514974 |
| (5) $(R_{3R1} + R_{3R2})/(R_{3R1} - R_{3R2})$ | — | −1.0000001 | −1.0000001 |
| (6) $('R_{3R1} + 'R_{3R2})/('R_{3R1} - 'R_{3R2})$ | 0.45203383 | — | — |
| (7) $fL/r_{SNr}$ | 0.16253301 | −0.4678714 | −0.3219041 |
| (8) $\nu_{31P} - \nu_{32P}$ | −47.75 | −26.16 | −26.16 |
| (9) $\nu_{33P} - (\nu_{31P} + \nu_{32P})/2$ | 23.875 | 13.08 | 13.08 |
| (10) $\nu_{31N} - \nu_{32N}$ | −9.46 | 0 | 0 |
| (11) $(R21F + R21R)/(R21F - R21R)$ | −7.5336864 | −11.658228 | −11.418687 |
| (12) $D21/fL$ | 0.56511087 | 0.71594012 | 0.60776379 |
| (13) $\beta2F$ | 1.11789 | 1.14373 | 1.16057 |
| (14) $\beta2N/\beta2F$ | 1.03937776 | 1.04814073 | 1.04766623 |
| (15) $(1 - \beta2F^2) \times \beta3F^2$ | 0.21089556 | 0.23210861 | 0.25010353 |
| (16) $(1 - \beta2N^2) \times \beta3N^2$ | 0.29567094 | 0.32926989 | 0.34487983 |
| (17) $fL/R12F_a$ | −0.1079795 | — | — |
| (18) $fL/R12F_b$ | −0.1079795 | — | — |
| (19) $fL/R12F_c$ | — | — | — |
| (20) $fL/R12F_d$ | — | −0.4888854 | −0.4207473 |
| (21) $fL/FL12$ | −0.1052367 | 0.13785028 | 0.03540806 |
| (22) $\lvert R_{fin}\rvert/\lvert f_{fin}\rvert$ | 0.35511155 | 19341611.3 | 23911431.8 |

-continued

| | | | |
|---|---|---|---|
| (23) $fL \times \tan\omega_{max}$ | 2.46301838 | 4.37275453 | 2.4579755 |
| $2y_{max}$ | 1.896 | 1.896 | 1.896 |
| (24) ER2 | 0.650 | 0.6 | 0.6 |
| $4 \times fL/F_{EX}$ | 0.87409997 | 0.85160331 | 0.88541886 |

| | Example10 | Example11 | Example12 |
|---|---|---|---|
| (1) f3L12/fL | 3.25109386 | 3.49339906 | 4.72851804 |
| (2) fL/R31F | 0.37218431 | 0.25378771 | 0.08561921 |
| (3) $fL \times \Sigma EP_{SNi}$ | −0.3755556 | −0.3324111 | −0.3045253 |
| (5) $(R_{3R1} + R_{3R2})/(R_{3R1} - R_{3R2})$ | −1.0000001 | −1.0000001 | −0.323504 |
| (6) $('R_{3R1} + 'R_{3R2})/('R_{3R1} - 'R_{3R2})$ | — | — | — |
| (7) $fL/r_{SNr}$ | 0.51932751 | 0.51080422 | 0.42114303 |
| (8) $\nu_{31P} - \nu_{32P}$ | −26.86 | −34.31 | −53.08 |
| (9) $\nu_{33P} - (\nu_{31P} + \nu_{32P})/2$ | 13.43 | 17.155 | 26.54 |
| (10) $\nu_{31N} - \nu_{32N}$ | −1.83 | 9.42 | 21.2 |
| (11) (R21F + R21R)/(R21F − R21R) | −11.566128 | −11.669683 | −5.1426732 |
| (12) D21/fL | 0.5485723 | 0.58524436 | 0.65323348 |
| (13) β2F | 1.07157 | 1.078 | 1.1682 |
| (14) β2N/β2F | 1.04339427 | 1.04698516 | 1.06389317 |
| (15) $(1 - \beta2F^2) \times \beta3F^2$ | 0.14865813 | 0.15410623 | 0.25030583 |
| (16) $(1 - \beta2N^2) \times \beta3N^2$ | 0.25074824 | 0.26037189 | 0.3738214 |
| (17) $fL/R12F_a$ | −0.0872652 | −0.1945591 | — |
| (18) $fL/R12F_b$ | −0.0872652 | −0.1945591 | — |
| (19) $fL/R12F_c$ | — | — | — |
| (20) $fL/R12F_d$ | — | — | — |
| (21) fL/FL12 | −0.118959 | −0.183571 | 0.0686298 |
| (22) $\lvert R_{fin}\rvert/\lvert f_{fin}\rvert$ | 15104827.4 | 7234895.27 | 1.437642 |
| (23) $fL \times \tan\omega_{max}$ | 2.41626746 | 2.38641257 | 2.15048988 |
| $2y_{max}$ | 1.896 | 1.896 | 1.624 |
| (24) ER2 | 0.65 | 0.65 | 0.728 |
| $4 \times fL/F_{EX}$ | 0.85698185 | 0.84479695 | 0.77760221 |

| | Example13 | Example14 |
|---|---|---|
| (1) f3L12/fL | 3.57594221 | 3.47974852 |
| (2) fL/R31F | 0.19138126 | 0.23847978 |
| (3) $fL \times \Sigma EP_{SNi}$ | −0.2114339 | −0.40739 |
| (5) $(R_{3R1} + R_{3R2})/(R_{3R1} - R_{3R2})$ | −1 | −1 |
| (6) $('R_{3R1} + 'R_{3R2})/('R_{3R1} - 'R_{3R2})$ | — | — |
| (7) $fL/r_{SNr}$ | −0.6046842 | −0.6132196 |
| (8) $\nu_{31P} - \nu_{32P}$ | 0 | −26.86 |
| (9) $\nu_{33P} - (\nu_{31P} + \nu_{32P})/2$ | −22.99 | 13.43 |
| (10) $\nu_{31N} - \nu_{32N}$ | — | −15.34 |
| (11) (R21F + R21R)/(R21F − R21R) | −17.411182 | −16.556019 |
| (12) D21/fL | 1.04169205 | 0.86736672 |
| (13) β2F | 1.21026 | 1.12026 |
| (14) β2N/β2F | 1.04413101 | 1.04524842 |
| (15) $(1 - \beta2F^2) \times \beta3F^2$ | 0.27768503 | 0.20935081 |
| (16) $(1 - \beta2N^2) \times \beta3N^2$ | 0.3566369 | 0.30470757 |
| (17) $fL/R12F_a$ | — | −0.2603177 |
| (18) $fL/R12F_b$ | −0.1938875 | −0.2603177 |
| (19) $fL/R12F_c$ | — | — |
| (20) $fL/R12F_d$ | — | — |
| (21) fL/FL12 | 0.02105524 | −0.0676638 |
| (22) $\lvert R_{fin}\rvert/\lvert f_{fin}\rvert$ | 43468810.7 | 43025556.8 |
| (23) $fL \times \tan\omega_{max}$ | 1.76552611 | 1.84324927 |
| $2y_{max}$ | 1.288 | 1.288 |
| (24) ER2 | 0.611 | 0.408 |
| $4 \times fL/F_{EX}$ | 0.61372863 | 0.64929138 |

FIG. **29** is an example of an image pickup apparatus. In this example, the image pickup apparatus is an endoscope system. FIG. **29** is a diagram showing a schematic configuration of an endoscope system.

An endoscope system **300** is an observation system in which an electronic endoscope is used. The endoscope system **300** includes an electronic endoscope **310** and an image processing unit **320**. The electronic endoscope **310** includes a scope section **310***a* and a connecting cord section **310***b*. Moreover, a display unit **330** is connected to the image processing unit **320**.

The scope section **310***a* is mainly divided into an operating portion **340** and an inserting portion **341**. The inserting portion **341** is long and slender, and can be inserted into a body cavity of a patient. Moreover, the inserting portion **341** is formed of a flexible member. An observer can carry out various operations by an angle knob that is provided to the operating portion **340**.

Moreover, the connecting cord section **310** b is extended from the operating portion **340**. The connecting cord section **301***b* includes a universal cord **350**. The universal cord **350** is connected to the image processing unit **320** via a connector **360**.

The universal cord **350** is used for transceiving of various types of signals. Various types of signals include signals such as a power-supply voltage signal and a CCD (charge coupled device) driving signal. These signals are transmitted from a power supply unit and a video processor to the scope section **310***a*. Moreover, various types of signals include a video signal. This signal is transmitted from the scope section **310***a* to the video processor.

Peripheral equipment such as a VTR (video tape recorder) deck and a video printer can be connected to the video processor inside the image processing unit **320**. The video processor carries out signal processing on a video signal from the scope section **310***a*. On the basis of the video signal, an endoscope image is displayed on a display screen of the display unit **330**.

An optical system is disposed at a front-end portion **342** of the inserting portion **341**. FIG. **30** is a diagram showing an arrangement of the optical system of the endoscope. An optical system **400** includes an illuminating section and an observation section.

The illuminating section includes a light guide **401** and an illuminating lens **402**. The light guide **401** transmits illumination light to the front-end portion **342** of the inserting portion **341**. The transmitted light is emerged from a front-end surface of the light guide **401**.

At the front-end portion **342**, the illuminating lens **402** is disposed. The illuminating lens **402** is disposed at a position of facing the front-end surface of the light guide **401**. The illumination light passes through the illuminating lens **402** and is emerged from an illumination window **403**. As a result, an observation object region **404** of an inside of an object (hereinafter, referred to as 'observation region **404**') is illuminated.

At the front-end portion **342**, an observation window **405** is disposed next to the illumination window **403**. Light from the observation region **404** is incident on the front-end portion **342** through the observation window **405**. An observation portion is disposed behind the observation window **405**.

The observation portion includes a wide-angle optical system **406** and an image sensor **407**. The wide-angle optical system of the example 1 is used for the wide-angle optical system **406**, for instance.

Reflected light from the observation region **404** passes through the wide-angle optical system **406** and is incident on the image sensor **407**. On an image pickup surface of the image sensor **407**, an image (an optical image) of the observation region **404** is formed. The image of the observation region **404** is converted photoelectrically by the image sensor **407**, and thereby an image of the observation region **404** is acquired. The image of the observation region **404** is displayed on the display unit **330**. By doing so, it is possible to observe the image of the observation region **404**

In the wide-angle optical system **406**, an image plane is curved shape. The image sensor **407** has a curved-shape light receiving surface (an image pickup surface) same as an shape of the image plane. By using the image sensor **407**, it is possible to improve an image quality of the acquired image.

FIG. **31** is a diagram showing an arrangement of an optical system of an image pickup apparatus. The optical system includes an objective optical system OBJ, a cover glass C, and a prism P. The cover glass C is disposed between the objective optical system OBJ and the prism P. The wide-angle optical system of the example 7 is used for the objective optical system OBJ. An optical filter may be disposed instead of the cover glass C. Or, the cover glass C may not be disposed.

The prism P includes a prims P**1** and a prism P**2**. Both the prism P**1** and the prism P**2** are triangular prisms. An optical-path splitting element is formed by the prism P**1** and the prism P**2**.

The prism P**1** has an optical surface S**1**, an optical surface S**2**, and an optical surface S**3**. The prism P**2** has an optical surface S**3**, an optical surface S**4**, and an optical surface S**5**. The prism P**1** is cemented to the prism P**2**. A cemented surface is formed by the prism P**1** and the prism P**2**. The optical surface S**3** is a cemented surface.

Light emerged from the objective optical system OBJ (hereinafter, referred to as 'imaging light') passes through the cover glass C, and is incident on the optical surface S**1**. The optical surface S**1** being a transmitting surface, the imaging light is transmitted through the optical surface S**1**.

Next, the imaging light is incident on the optical surface S**3**. The optical surface S**3** is disposed so that a normal of the surface is at 45 degrees with respect to an optical axis. The imaging light incident on the optical surface S**3** is divided into light transmitted through the optical surface S**3** (hereinafter, referred to as 'imaging light **1**') and light reflected at the optical surface S**3** (hereinafter, referred to as 'imaging light **2**').

The imaging light **1** and the imaging light **2** travel in mutually different directions. When an optical path through which the imaging light **1** travels is a first optical path and an optical path through which the imaging light **2** travels is a second optical path, the first optical path and the second optical path are formed by the optical surface S**3**. As just described, the optical surface S**3** functions as an optical-path splitting surface.

The first optical path is formed on an extension line of an optical path of the objective optical system OBJ. The second optical path is formed to intersect the first optical path. In FIG. **31**, the second optical path is orthogonal to the first optical path.

The optical surface S**3**, the optical surface S**4**, and the optical surface S**5** are located in the first optical path. The imaging light **1** transmitted through the optical surface S**3** is incident on the optical surface S**4**. The optical surface S**4** is a reflecting surface. The imaging light **1** is reflected at the optical surface S**4**, and is incident on the optical surface S**5**. The optical surface S**5** is a transmitting surface. The imaging light **1** is transmitted through the optical surface S**5**, and is converged on an image plane I near the optical surface S**5**. An optical image by the imaging light **1** is formed on the image plane I.

The optical surface S**3**, the optical surface S**2**, the optical surface S**3**, and the optical surface S**5** are located in the second optical path. The imaging light **2** reflected at the optical surface **S3** is incident on the optical surface **S2**. The optical surface **S2** is a reflecting surface. The imaging light **2** is reflected at the optical surface **S2**, and is incident on the optical surface **S3**. At the optical surface **S3**, the imaging light **2** is divided into light transmitted through the optical surface **S3** and light reflected at the optical surface **S3**.

The imaging light **2** transmitted through the optical surface **S3** is incident on the optical surface **S5**. The imaging light **2** is transmitted through the optical surface **S5**, and is converged on the image plane I near the optical surface **S5**. An optical image by the imaging light **2** is formed on the image plane I.

Since two optical paths are formed in the optical system shown in FIG. **31**, two optical images are formed on the same plane. The same plane is the image plane I in the two optical paths.

In a case in which an optical-path length of the first optical path and an optical-path length of the second optical path are same, two focused optical images are formed at different positions on the same plane. The two optical images are optical images when the same object is focused. Accordingly, a position of an object plane for one optical image and a position of an object plane for the other optical image are same.

Whereas, even in a case in which the optical-path length of the first optical path and the optical-path length of the second optical path are different, two focused optical images are formed at different positions on the same plane. However, the two optical images are optical images when different objects are focused.

Accordingly, a position of an object plane for one optical image and a position of an object plane for the other optical image are different.

For instance, it is assumed that the optical-path length of the first optical path is shorter than the optical-path length of the second optical path. In this case, the object plane of the optical image formed by the imaging light **1** is positioned far from the object plane of the optical image formed by the imaging light **2**. As just described, the focus is adjusted for each of the two object planes in which distance from the objective optical system (hereinafter, referred to as 'object distance') differs from each other. Even when the object distance differs for two object planes, the two optical images are formed at different locations in on the same plane.

The objective optical system OBJ has a section which is focused (hereinafter, referred to as 'focusing section'). The focusing section is a section expressed by the object distance, and corresponds to a depth of field of the objective optical system OBJ. In the focusing section, wherever the object plane is positioned, a focused optical image is formed.

In a case in which the object distance differs for two object planes, there occurs a shift between a position of the focusing section for one object plane and a position of the focusing section for the other object plane. By setting appropriately the distance of the two object planes, it is possible to overlap a part of the focusing section for the one object plane and a part of the focusing section for the other object plane.

Thus, two optical images having the focusing section shifted are captured, and accordingly, two images are acquired. Moreover, only a focused area (an image area of a range corresponding to the depth of field) is extracted from the two images that were acquired, and the areas extracted are combined. By doing so, it is possible to acquire an image with a large depth of field.

For the optical surface S3, it is possible to use a half-mirror surface or a polarizing-beam splitter surface for example.

In a case in which the optical surface **S3** is a half-mirror surface, a half of a quantity of imaging light is reflected at the optical surface **S3** and the remaining half of the quantity of imaging light is transmitted through the optical surface **S3**. Accordingly, a quantity of the imaging light **2** becomes half of the quantity of the imaging light. The imaging light **2** is reflected at the optical surface **S2**. The imaging light **2** reflected at the optical surface **S2** is transmitted through the optical surface **S3**. At the optical surface **S3**, only half of the quantity of the imaging light **2** can be transmitted.

In a case in which the optical surface **S3** is a polarizing-beam splitter surface, a depolarization plate or a wavelength plate may be used instead of the cover glass C. Moreover, the optical surface **S2** is not a reflecting surface but is a transmitting surface. A reflecting surface is disposed at a position away from the optical surface **S2**. Furthermore, a quarter-wave plate is disposed between the optical surface **S2** and the reflecting surface.

P-polarized light is polarized light having an amplitude of light in a paper plane, and S-polarized light is polarized light having an amplitude in a plane orthogonal to the paper plane. When it is assumed that the P-polarized light is transmitted through the optical surface **S3** and the S-polarized light is reflected at the optical surface **S3**, the P-polarized light corresponds to the imaging light **1** and the S-polarized light corresponds to the imaging light **2**.

For instance, when the depolarization plate is used instead of the cover glass C, the imaging light passes through the depolarization plate. Consequently, in the imaging light emerged from the depolarization plate, a proportion of the P-polarized light and the S-polarized light in the imaging light becomes substantially half. The imaging light incident on the optical surface **S3** is divided into the P-polarized light and the S-polarized light at the optical surface **S3**. Accordingly, the quantity of the imaging light **2** becomes half of the quantity of the imaging light.

The imaging light **2**, when directed from the optical surface **S3** toward the optical surface **S2**, is S-polarized light. In a case in which the optical surface **S2** is a reflecting surface, the imaging light **2** is reflected toward the optical surface **3** as the S-polarized light as it has been. The imaging light **2** directed from the optical surface **S2** toward the optical surface **S3** being the S-polarized light, cannot be transmitted through the optical surface **S3**.

Whereas, in a case in which the optical surface **S2** is a transmitting surface, the imaging light **2** is reflected at the reflecting surface. The λ/4 plate is disposed between the optical surface **S2** and the reflecting surface. By the imaging light **2** travelling to and from between the optical surface **S2** and the reflecting surface, a direction of polarization for the imaging light **2** rotates 90 degrees. Accordingly, it is possible to convert the S-polarized light to the P-polarized light. As a result, the imaging light directed from the optical surface **S2** toward the optical surface **S3** becomes the P-polarized light.

The imaging light **2** converted to the P-polarized light reaches the optical surface **S3**. Accordingly, the imaging light **2** is not reflected at the optical surface **S3**. In other words, at the optical surface **S3**, almost whole of the amount of the imaging light **2** can be transmitted through.

FIG. **32**A and FIG. **32**B are diagrams showing a schematic configuration of an image pickup apparatus. FIG. **32**A is a diagram showing an overall configuration, and FIG. **32**B is a diagram showing an orientation of an object.

As shown in FIG. **32**A, an image pickup apparatus **500** includes an objective optical system **501**, a depolarization plate **502**, a first prism **503**, a second prism **504**, a third prism **505**, a wavelength plate **506**, a mirror **507**, an image sensor **508**, an image processor **511**, and an image display unit **512**.

In the image pickup apparatus **500**, an optical-path splitting element is formed by the first prism **503**, the second prism **504**, and the third prism **505**.

The objective optical system **501** forms an image of an object. The depolarization plate **502** is disposed between the objective optical system **501** and the first prism **503**.

The first prism **503** and the second prism **504** are cemented. A cemented surface **509** is formed by the first prism **503** and the second prism **504**. Light incident on the cemented surface **509** is divided into light reflected at the cemented surface **509** and light transmitted through the cemented surface **509**.

It is possible to use a polarizing-beam splitter surface for the cemented surface **509**. In this case, P-polarized light is transmitted through the cemented surface **509** and S-polarized light is reflected at the cemented surface **509**.

The P-polarized light transmitted through the cemented surface **509** emerges from the second prism **504**. The P-polarized light is incident on the third prism **505** and reaches an optical surface **510**. The optical surface **510**, for instance, is a mirror surface. Accordingly, the P-polarized light is reflected at the optical surface **510**.

The P-polarized light reflected at the optical surface **510** emerges from the third prism **505** and is incident on the image sensor **508**. As shown in FIG. **32**B, the image sensor **508** has a first area **513** and a second area **514**. The P-polarized light reflected at the optical surface **510** is incident on the first area **513**. Accordingly, an optical image is formed on the first area **513**.

On the other hand, the S-polarized light reflected at the cemented surface **509** emerges from the first prism **503**. The S-polarized light is incident on the wavelength plate **506**. A quarter-wave plate is used for the wavelength plate **506**. Consequently, the S-polarized light is converted to circularly-polarized light at the wavelength plate **506**. As a result, the circularly-polarized light emerges from the wavelength plate **506**.

The circularly-polarized light is reflected at the mirror **507** and is incident once again on the wavelength plate **506**. Light emerged from the wavelength plate **506** is incident on the first prism **503** and reaches the cemented surface **509**. The circularly-polarized light incident on the wavelength plate **506** is converted to P-polarized light at the wavelength plate **506**. The light reached the cemented surface **509** being the P-polarized light, the light reached the cemented surface **509** is transmitted through the cemented surface **509**.

The P-polarized light which is transmitted through the cemented surface **509** emerges from the second prism **504** and is incident on the image sensor **508**. As mentioned above, the image sensor **508** has the first area **513** and the second area **514**. The P-polarized light transmitted through the cemented surface **509** is incident on the second area **514**. As a result, an optical image is formed on the second surface **514**.

For instance, a rolling shutter system is adopted for the image sensor **508**. In the rolling shutter system, image information for a line is read for each line one-by-one. The image sensor **508** is connected to the image processor **511**. Image information which is read is input to the image processor **511**.

The image processor **511** includes a second image processing section **511***b*. In the second image processing section **511***b*, it is possible to select a focused image as an image for display by using the image information that has been read for each line one-by-one. Images for each line selected by the second image processing section **511***b* are combined and displayed on the image display unit **512**.

The image processor **511** will be described below. The image processor **511** is provided to a central processing unit (not shown in the diagram). The image processor **511** includes a first image processing section **511***a*, the second image processing section **511***b*, a third image processing section **511***c*, a fourth image processing section **511***d*, and a fifth image processing section **511***e*.

In the first image processing section **511***a*, an orientation of an image acquired from the first area **513** (hereinafter, referred to as 'first image') and an orientation of an image acquired from the second area **514** (hereinafter, referred to as 'second image') are corrected. In correction of the orientation of the image, the image is rotated for example.

The orientation of the first image and the orientation of the second image are determined by an orientation of the optical image formed in the first area **513** (hereinafter, referred to as 'first optical image') and an orientation of the optical image formed in the second area **514** (hereinafter, referred to as 'second optical image') respectively.

FIG. **33** is a diagram showing a positional relationship of an object, an objective optical system, and an optical-path splitting element. For instance, a case of observing a character 'F' as shown in FIG. **33** will be described below. Each of the orientation of the first optical image and the orientation of the second optical image is an orientation as shown in FIG. **32**B.

As shown in FIG. **32**B, the first optical image and the second optical image are mirror images of each other. Furthermore, when a vertical orientation of a paper surface is an upright direction, the first optical image and the second optical image are rotated 90 degrees from the upright direction.

Therefore, in a case of displaying an image of an object on the image display unit **512**, in the first image processing section **511***a*, the first image is rotated 90 degrees with a central point of the first area **513** as a center. Even regarding the second image, the second image is rotated 90 degrees with a central point of the area **514** as a center. Moreover, regarding the second image, the second image is inverted, and a mirror image is corrected.

As the processing by the first image processing section **511***a* is terminated, processing by the second image processing unit **511***b* is executed. However, according to the requirement, processing by at least one of the third image processing section **511***c*, the fourth image processing section **511***d*, and the fifth image processing section **511***e* may be executed before executing the processing by the second image processing section **511***b*.

The third image processing section **511***c* is configured so that a white balance of the first image and a white balance of the second image are adjustable. The fourth image processing section **511***d* is configured so that a center position of the first image and a center position of the second image are movable or selectable. The fifth image processing section **511***e* is configured so that a display range of the first image and a display range of the second image are adjustable. Moreover, the fifth image processing section **511***e* may be configured so that a display magnification is adjustable instead of the display range.

The second image processing section **511***b* is configured to compare the first image and the second image, and to select an image of a focused area as an image for display.

The second image processing section **511***b* has a high-pass filter, a comparator, and a switch. The high-pass filter is connected to each of the first area **513** and the second area **514**. In the high-pass filter, a high component is extracted from each of the first image and the second image.

Outputs of the two high-pass filters are input to the comparator. The high components extracted in the two high-pass filters are compared in the comparator. A comparison result is input to the switch. Moreover, the first area **513** and the second area **514** are connected to the switch. Accordingly, the comparison result, a signal of the first image, and a signal of the second image are input to the switch.

In the switch, an area with many high component in the first image and an area with many high component in the second image are selected on the basis of the comparison result.

The image display unit **512** has a display area. An image selected by the second processing section **511***b* is displayed in the display area. The image display unit **512** may have display areas displaying the first image and the second image.

According to the present disclosure, it is possible to provide a wide-angle optical system in which various aberrations are corrected favorably, and which an outer diameter of a lens which moves and an outer diameter of a lens located near a lens unit that moves are adequately small, and an image pickup apparatus in which the wide-angle optical system is used.

As described heretofore, the present disclosure is suitable for a wide-angle optical system in which various aberrations are corrected favorably, and which an outer diameter of a lens which moves and an outer diameter of a lens located near a lens unit that moves are adequately small, and an image pickup apparatus in which the wide-angle optical system is used.

What is claimed is:

**1**. A wide-angle optical system having a lens component which has a plurality of optical surfaces, and in the lens component, two optical surfaces are in contact with air, and at least one optical surface is a curved surface, the wide-angle optical system comprising, in order from an object side:

a first lens unit having a negative refractive power;

a second lens unit having a positive refractive power; and

a third lens unit having a positive refractive power,

wherein:

at a time of carrying out a focal-position adjustment from a far point to a near point, the second lens unit is moved from a first position toward a second position, the first position being a position at which a distance between the first lens unit and the second lens unit becomes minimum, and the second position being a position at which a distance between the second lens unit and the third lens unit becomes minimum,

the third lens unit includes at least three lens components, the at least three lens components including a first lens component and a second lens component, the first lens component being a lens component located nearest to an object in the third lens unit, and the second lens component being a lens component located second from the object side in the third lens unit,

each of the first lens component and the second lens component has a positive refractive power,

the third lens unit includes at least three cemented surfaces,

a value of a difference in refractive indices is not less than 0.25 at each of the at least three cemented surfaces, and

the following conditional expression (1) is satisfied:

$$0.8<f3L12/fL<6.0 \qquad (1)$$

where,

f3L12 denotes a combined focal length of the first lens component and the second lens component,

fL denotes a focal length of the wide-angle optical system at the first position,

the difference in refractive indices is a difference between an object-side refractive index and an image-side refractive index,

the object-side refractive index is a refractive index for a d-line of a medium which is located on an object side of the cemented surface, and which is adjacent to the cemented surface, and

the image-side refractive index is a refractive index for a d-line of a medium which is located on an image side of the cemented surface, and which is adjacent to the cemented surface.

**2**. The wide-angle optical system according to claim **1**, wherein at least two diverging surfaces are disposed between a surface nearest to the object of the first lens component and a surface nearest to an image of the second lens component.

**3**. The wide-angle optical system according to claim **1**, wherein the third lens unit includes at least four lens components.

**4**. The wide-angle optical system according to claim **1**, wherein the third lens unit includes three, four, or five lens components having a positive refractive power.

**5**. The wide-angle optical system according to claim **1**, wherein a cemented lens located nearest to an image in the third lens unit includes, in order from the object side, a positive lens and a negative lens.

**6**. The wide-angle optical system according to claim **1**, wherein

a single lens unit is disposed nearest to an image in the third lens unit,

the single lens unit includes two single lenses or three single lenses,

a cemented lens is disposed adjacent to the single lens unit, on the object side of the single lens unit, and

the cemented lens includes, in order from the object side, a positive lens and a negative lens.

**7**. The wide-angle optical system according to claim **1**, wherein:

one single lens is disposed nearest to an image in the third lens unit,

a cemented lens is disposed adjacent to the single lens, on the object side of the single lens, and

the cemented lens includes, in order from the object side, a positive lens and a negative lens.

**8**. The wide-angle optical system according to claim **1**, wherein the following conditional expression (2) is satisfied:

$$0.05<fL/R31F<1.20 \qquad (2)$$

where R31 F denotes a radius of curvature of a surface on the object side of the first lens component.

**9**. The wide-angle optical system according to claim **1**, further comprising:

an image-side lens component,

wherein:

the image-side lens component, among a plurality of lens components of the wide-angle optical system, is a lens component located nearest to an image, the third lens unit includes N number of cemented surfaces $S_{Ni}$ (i=1, 2, . . . N) between the first lens component and the image-side lens component, and the following conditional expression (3) is satisfied:

$$-1.0<fL\times\Sigma P_{SNi}<-0.05 \quad (3)$$

where,

$P_{SNi}$ denotes a refractive power of the cemented surface $S_{Ni}$, and is expressed by the following expression (4):

$$P_{SNi}=(n_{SNi}-n_{SNi})/r_{SNi} \quad (4)$$

where,

$n_{SNi}$ denotes a refractive index for a d-line of a medium located on the object side of the cemented surface $S_{Ni}$,

$n^{SNi'}$ denotes a refractive index for the d-line of a medium located on the image side of the cemented surface $S_{Ni}$, and

$r_{SNi}$ denotes a radius of curvature near an optical axis of the cemented surface $S_{Ni}$.

**10**. The wide-angle optical system according to claim **1**, wherein:

the third lens unit includes a cemented lens which is located nearest to an image among a plurality of cemented lenses, and a lens component which is located nearest to the image,

the cemented lens which is located nearest to the image has a positive refractive power,

the lens component which is located nearest to the image is a positive single lens, and

the following conditional expression (5) is satisfied:

$$-2<(R_{3R1}+R_{3R2})/(R_{3R1}-R_{3R2})<2 \quad (5)$$

where,

$R_{3R1}$ denotes a radius of curvature of a surface on the object side of the positive single lens, and

$R_{3R2}$ denotes a radius of curvature of a surface on the image side of the positive single lens.

**11**. The wide-angle optical system according to claim **1**, wherein:

the third lens unit includes a cemented lens which is located nearest to an image among a plurality of cemented lenses, and a positive single lens satisfy which is located nearest to the image,

the cemented lens which is located nearest to the image has a negative refractive power, and

the following conditional expression (6) is satisfied:

$$-5<('R_{3R1}+'R_{3R2})/('R_{3R1}-'R_{3R2})<1 \quad (6)$$

where,

$'R_{3R1}$ denotes a radius of curvature of a surface on the object side of the positive single lens, and

$'R_{3R2}$ denotes a radius of curvature of a surface on the image side of the positive single lens.

**12**. The wide-angle optical system according to claim **1**, wherein a cemented surface located nearest to an image in the third lens unit satisfies the following conditional expression (7)

$$-2.0<fL/r_{SNr}<1.5 \quad (7)$$

where,

$r_{SNr}$ denotes a radius of curvature near an optical axis of the cemented surface located nearest to the image.

**13**. The wide-angle optical system according to claim **1**, wherein:

the third lens unit includes a plurality of positive lenses,

the plurality of positive lenses include a first positive lens and a second positive lens,

the first positive lens, among the plurality of positive lenses, is a positive lens located nearest to the object,

the second positive lens, among the plurality of positive lenses, is a positive lens located second from the object, and

the following conditional expression (8) is satisfied:

$$-70<\nu_{31P}-\nu_{32P}<20 \quad (8)$$

where,

$\nu_{31P}$ denotes an Abbe number for the first positive lens, and

$\nu_{32P}$ denotes an Abbe number for the second positive lens.

**14**. The wide-angle optical system according to claim **1**, wherein:

the third lens unit includes a plurality of positive lenses,

the plurality of positive lenses include a first positive lens, a second positive lens, and a third positive lens,

the first positive lens, among the plurality of positive lenses, is a positive lens located nearest to the object,

the second positive lens, among the plurality of positive lenses, is a positive lens located second from the object,

the third positive lens, among the plurality of positive lenses, is a positive lens located third from the object, and

the following conditional expression (9) is satisfied:

$$-50<\nu_{33P}-(\nu_{31P}+\nu_{32P})/2<80 \quad (9)$$

where,

$\nu_{31P}$ denotes an Abbe number for the first positive lens,

$\nu_{32P}$ denotes an Abbe number for the second positive lens, and

$\nu_{33P}$ denotes an Abbe number for the third positive lens.

**15**. The wide-angle optical system according to claim **1**, wherein:

the third lens unit includes a plurality of negative lenses,

the plurality of negative lenses include a first negative lens and a second negative lens,

the first negative lens, among the plurality of negative lenses, is a negative lens located nearest to the object,

the second negative lens, among the plurality of negative lenses, is a negative lens located second from the object, and

the following conditional expression (10) is satisfied:

$$-40<\nu_{31N}-\nu_{32N}<50 \quad (10)$$

where,

$\nu_{31N}$ denotes an Abbe number for the first negative lens, and

$\nu_{32N}$ denotes an Abbe number for the second negative lens.

**16**. The wide-angle optical system according to claim **1**, wherein the third lens unit is fixed at the time of carrying out the focal-position adjustment.

**17**. The wide-angle optical system according to claim **1**, wherein the following conditional expression (11) is satisfied:

$$-60<(R21F+R21R)/(R21F-R21R)<1 \quad (11)$$

where,

R21 F denotes a radius of curvature of a surface on the object side of a predetermined lens component,

R21 R denotes a radius of curvature of a surface on h image side of the predetermined lens component, and

the predetermined lens component is a lens component located nearest to the object in the second lens unit.

**18**. The wide-angle optical system according to claim **1**, wherein the following conditional expression (12) is satisfied:

$$0.2<D21/fL<3.0 \tag{12}$$

where D21 denotes a distance on an optical axis between a surface nearest to the object and a surface nearest to an image of the second lens unit.

**19**. The wide-angle optical system according to claim **1**, wherein the following conditional expression (13) is satisfied:

$$1.01<\beta 2F<1.35 \tag{13}$$

where β2F denotes a magnification of the second lens unit at the first position.

**20**. The wide-angle optical system according to claim **1**, wherein the following conditional expression (14) is satisfied:

$$1.01<\beta 2N/\beta 2F<1.15 \tag{14}$$

where,

β2F denotes a magnification of the second lens unit at the first position, and

β2N denotes a magnification of the second lens unit at the second position.

**21**. The wide-angle optical system according to claim **1**, wherein the following conditional expression (15) is satisfied:

$$0.08<(1-\beta 2F^2)\times\beta 3F^2<0.45 \tag{15}$$

where,

β2F denotes a magnification of the second lens unit at the first position, and

β3F denotes a magnification of the third lens unit at the first position.

**22**. The wide-angle optical system according to claim **1**, wherein the following conditional expression (16) is satisfied:

$$0.15<(1-\beta 2N^2)\times\beta 3N^2<0.55 \tag{16}$$

where,

β2N denotes a magnification of the second lens unit at the second position, and

β3N denotes a magnification of the third lens unit at the second position.

**23**. The wide-angle optical system according to claim **1**, wherein the second lens unit includes only a positive lens.

**24**. A wide-angle optical system having a lens component which has a plurality of optical surfaces, and in the lens component, two optical surfaces are in contact with air, and at least one optical surface is a curved surface, the wide-angle optical system comprising, in order from an object side:

a first lens unit having a negative refractive power;

a second lens unit having a positive refractive power; and

a third lens unit having a positive refractive power, wherein:

at a time of carrying out a focal-position adjustment from a far point to a near point, the second lens unit is moved from a first position toward a second position, the first position being a position at which a distance between the first lens unit and the second lens unit becomes minimum, and the second position being a position at which a distance between the second lens unit and the third lens unit becomes minimum,

the third lens unit includes at least three lens components, the at least three lens components including a first lens component and a second lens component, the first lens component being a lens component located nearest to an object in the third lens unit, and the second lens component being a lens component located second from the object side in the third lens unit,

each of the first lens component and the second lens component has a positive refractive power,

the first lens unit includes only a negative lens,

the negative lens has an Abbe number larger than an Abbe number for a positive lens nearest to the object in the third lens unit and

the following conditional expression (1) is satisfied:

$$0.8<f3L12/fL<6.0 \tag{1}$$

where,

f3L12 denotes a combined focal length of the first lens component and the second lens component, and

fL denotes a focal length of the wide-angle optical system at the first position.

**25**. The wide-angle optical system according to claim **1**, wherein:

the first lens unit includes a plurality of negative lens components,

the plurality of negative lens components include a first negative lens component and a second negative lens component,

the second negative lens component, among the plurality of negative lens components, is a negative lens component located second from the object, and

the following conditional expression (17) is satisfied:

$$-2.0<fL/R12F_a<5.0 \tag{17}$$

where $R12F_a$ denotes a radius of curvature of a surface on the object side of the second negative lens component.

**26**. The wide-angle optical system according to claim **1**, wherein:

the first lens unit includes a fourth lens component and a fifth lens component,

the fourth lens component is a lens component located nearest to the object in the first lens unit,

the fifth lens component is a lens component located second from the object side in the first lens unit,

the fourth lens component includes a negative lens component,

the fifth lens component includes a cemented lens, and

the following conditional expression (18) is satisfied:

$$-1.0<fL/R12F_b<0.5 \tag{18}$$

where $R12F_b$ denotes a radius of curvature of a surface on the object side of the fifth lens component.

**27**. The wide-angle optical system according to claim **1**, wherein:

the first lens unit includes a fourth lens component, a fifth lens component, and a sixth lens component,

the fourth lens component is a lens component located nearest to the object in the first lens unit,

the fifth lens component is a lens component located second from the object side in the first lens unit,

the sixth lens component is a lens component located third from the object side in the first lens unit,

the fourth lens component includes a negative lens component,

the fifth lens component includes a negative lens component,

the sixth lens component includes a positive lens component, and the following conditional expression (19) is satisfied:

$$-1.0<fL/R12F_c<0.4 \tag{19}$$

where $R12F_c$ denotes a radius of curvature of a surface on the object side of the fifth lens component.

**28**. The wide-angle optical system according to claim **1**, wherein:

the first lens unit includes a fourth lens component, a fifth lens component, and a sixth lens component,

the fourth lens component is a lens component located nearest to the object in the first lens unit,

the fifth lens component is a lens component located second from the object side in the first lens unit,

the sixth lens component is a lens component located third from the object side in the first lens unit,

the fourth lens component includes a negative lens component,

the fifth lens component includes a lens component for which an absolute value of a refractive power is smaller than an absolute value of a refractive power of the fourth lens component,

the sixth lens component includes a cemented lens, and

the following conditional expression (20) is satisfied:

$$-1.2<fL/R12F_d<0.2 \quad (20)$$

where $R12F_d$ denotes a radius of curvature of a surface on the object side of the sixth lens component.

**29**. The wide-angle optical system according to claim **1**, wherein:

the first lens unit includes a fourth lens component and a fifth lens component,

the fourth lens component is a lens component located nearest to the object in the first lens unit,

the fifth lens component is a lens component located second from the object side in the first lens unit, and

the following conditional expression (21) is satisfied:

$$-1.0<fL/fL12<0.4 \quad (21)$$

where fL12 denotes a focal length of the fifth lens component.

**30**. The wide-angle optical system according to claim **1**, further comprising:

an image-side lens component,

wherein:

the image-side lens component, among a plurality of lens components of the wide-angle optical system, is a lens component located nearest to an image, and the following conditional expression (22) is satisfied:

$$100\times|f_{fin}|<|R_{fin}| \quad (22)$$

where,

$f_{fin}$ denotes a focal length of an image-side lens component, and

$R_{fin}$ denotes a radius of curvature of a surface on the image side of the image-side lens component.

**31**. The wide-angle optical system according to claim **1**, further comprising:

an image-side lens component; and

an optical element having zero refractive power,

wherein:

the image-side lens component, among a plurality of lens components of the wide-angle optical system, is a lens component located nearest to an image,

the optical element is located on h image side of the image-side lens component, and

the image-side lens component and the optical element are cemented.

**32**. The wide-angle optical system according to claim **1**, wherein the following conditional expression (23) is satisfied:

$$2\times y_{max}<fL\times\tan\omega_{max} \quad (23)$$

where,

$y_{max}$ denotes a maximum image height, and

$\omega_{max}$ denotes an angle of view corresponding to the maximum image height.

**33**. The wide-angle optical system according to claim **1**, wherein the following conditional expression (24) is satisfied:

$$ER2<4\times fL/F_{EX} \quad (24)$$

where,

ER2 denotes an effective radius of a surface nearest to an image of the second lens component, and

$F_{EX}$ denotes an effective F-value at the first position.

**34**. An image pickup apparatus comprising:

an optical system; and

an image sensor which is disposed on an image plane,

wherein:

the image sensor has an image pickup surface, and converts an image formed on the image pickup surface by the optical system to an electric signal, and

the optical system is the wide-angle optical system according to claim **1**.

* * * * *